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THESIS

METHODOLOGY FOR BENEFIT ANALYSIS
OF CAD/CAM IN USN SHIPYARDS

by

Richard B. Grahlman

March 1984

Thesis Advisor: R. Kevin Wood

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This thesis expands the concept of Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) in naval shipbuilding to include maintenance. This inclusion is coupled with the integration of the design and manufacturing processes in the acronym CIDMM, which stands for Computer-Integrated Design, Manufacture and Maintenance.

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Methodology for Benefit Analysis of CAD/CAM in USN Shipyards

by

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Lieutenant Commander, United States Navy
B.S., Oregon State University, 1976

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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ABSTRACT

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TABLE OF CONTENTS

I. INTRODUCTION 10
A. PRODUCTIVITY IN THE U.S. 10
B. PRODUCTIVITY IN U.S. NAVAL SHIPBUILDING . . . 11
C. CURRENT TECHNOLOGY & SHIPBUILDING 14
D. U.S. NAVAL SHIPYARDS & CURRENT TECHNOLOGY . . 14

II. A BRIEF HISTORY OF CAD/CAM 17
A. BACKGROUND 17
B. THE FIRST GENERATION OF CAD/CAM 17
C. THE SECOND GENERATION OF CAD/CAM 19
D. THE THIRD GENERATION OF CAD/CAM 20

III. CIDMM, THE NEXT GENERATION 23
A. INTEGRATION OF DESIGN, MANUFACTURING AND MAINTENANCE 23
B. SHIPBUILDING, CIDMM, AND THE FUTURE 28

IV. DISCUSSION OF EXISTING BENEFIT METHODOLOGIES . . . 30
A. OVERVIEW 30
B. EXISTING BENEFIT ANALYSIS METHODOLOGIES . . . 31
1. Chasen's Method (as applied by Long Beach N.S.) 31
2. Shah & Yan's Method 34
3. CAEDOS Productivity Measurement Method . . 36
4. Packer and Kahn's Method 39

V. GRAHLMAN'S METHOD 48
A. MOTIVATION 48
B. TANGIBLE BENEFIT QUANTIFICATION 51
1. Quality 58

2. Flexibility 59
3. Accuracy 59
4. Transferability 59
5. Automization 60
6. Simulation 60
C. INTANGIBLE BENEFIT ANALYSIS 64
1. Rethinking of Design, Methods 65
2. More Efficient Work Scheduling 66
3. Technical Publication Changes 67
4. Improved Accuracy in Fabrication 68
5. Refine and Improve Work Methods 69
6. Communication/Cohesiveness 70
7. Engineering Data-base for Life-Cycle Management 71
8. Quality of Engineering Personnel 71
D. OTHER BENEFITS 72
1. Reduced Material Wastes 72
2. Manpower/Workload Fluctuations 73
3. Paper Elimination 73
4. The Cutting Edge of Technology 74
E. SUMMARY 75

VI. FORMAL METHODCLOGY 76
A. OVERVIEW 76
B. TANGIBLE BENEFIT ANALYSIS USING THE GENERIC FRAMEWORK 76
1. Data Collection 76
2. Analysis 79
C. INTANGIBLE BENEFIT ANALYSIS 81
1. Data Collection and Analysis 81
D. "OTHER" BENEFIT ANALYSIS 81
1. Data Collection and Analysis 81
E. SUMMARY 82

LIST OF REFERENCES 84

INITIAL DISTRIBUTION LIST 86

LIST OF TABLES

I. Proposed Five-Year Naval Shipbuilding Plan 13

II. Variables in Order of Their Greatest Cluster Loading 42

III. Relevant Benefits of CAD/CAM 50

IV. Relevant Benefits of The Status Quo 51

LIST OF FIGURES

1.1 Typical Interim CAD/CAM System Configuration . . 16
2.1 The First Generation 18
2.2 The Second Generation 20
2.3 The Third Generation 21
3.1 Manual Approach 25
3.2 CIDMM Approach 26
4.1 Perceptual Map 43
4.2 Perceptual Differences 45
4.3 System Comparison 46
5.1 Time Flow for Generating An Elementary Design 52
5.2 Time Required to Program One Tool Detail 53
5.3 Sample Data Reduction Scheme 56
5.4 Data Reduction With Subsets Included 63
6.1 Computervision Learning Curve 78
6.2 Methodology Flowchart 83

I. INTRODUCTION

This thesis presents a methodology to analyze the benefits derived from present Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) Systems or from future Computer Integrated Design, Manufacture and Maintenance (CIDMM) Systems. It was developed in response to a requirement to document the actual benefits derived from the Interim CAD/CAM Systems being used at the eight U.S. naval shipyards. The methodology provides a vehicle to measure the tangible benefits such as time, material and manpower savings and the intangible benefits such as quality, worker satisfaction and readiness. The underlying motivation for examining this technology is the interest in improving productivity where possible. We will begin by examining productivity in the United States.

A. PRODUCTIVITY IN THE U.S.

Productivity and productivity measurement are topics of great concern in the U.S. today. Former Deputy Secretary of Defense, Paul W. Thayer, states: [Ref. 1: pp. 3]

> "Improving productivity is one of the most formidable challenges facing America and the Defense Department today. It affects our economic well-being and our national security. After a rude awakening in the international marketplace, we can no longer be complacent about the continued productive superiority of the United States. Today our technological leadership is challenged across a broad range of processes and products.
>
> America still has the most highly skilled and talented work force in the world, and we maintain the highest level of output per worker of any country in the world. But recently there has been a disturbing decline in the rate of productivity growth. The Department of Defense has a special interest in reversing that trend, particularly as it affects developing and building complex sophisticated weapon systems to meet national security objectives.

> With expanding commitments but limited resources, the Defense Department must improve productivity to sustain a strong deterrent force and maintain a high degree of readiness."

Clearly, improving productivity in DOD is important. One of the areas hardest hit by this productivity decline, and an area with substantial impact on sustaining a "strong deterrent force" and maintaining a "high degree of readiness" is shipbuilding and repair. It is estimated that "productivity in the best Japanese and Scandinavian yards is of the order of 100 percent better than in good U.S. or U.K. shipyards" [Ref. 2]. Although this statement refers to merchant and not naval construction, a 2:1 edge in productivity is indicative of the U.S. shipyards lack of use of the state-of-the-art technology.

B. PRODUCTIVITY IN U.S. NAVAL SHIPBUILDING

Examining U.S. naval shipbuilding and repair cannot really be done separately from general shipbuilding and repair as the two are closely related. "A low level of Navy orders in the past was normally offset by a high level of commercial orders and vice versa" [Ref. 3: pp. 12]. The current economic climate and foreign competition has reduced commercial orders to a point where naval ship construction and repair will predominate for some time. This predominance creates productivity problems for the shipbuilders who have to shift to a very different type of construction. While the fundamental naval architecture and marine engineering principles are the same, the complexity of design and construction of naval ships is significantly greater both from a technical and administrative viewpoint.

A Naval Ship is a totally integrated weapon system where space, weight and survivability are carefully balanced factors. A commercial ship, on the other hand, has large

volumes of space, small crews, and generally simpler equipment. Administratively the Navy requires much more extensive contracts, work monitoring and customer approval than do commercial buyers. This means that Navy Ships are much more expensive and time-consuming to build than commercial craft.

The existence of government-owned shipyards further compounds the problem of having to build ships for the Navy which are more expensive and time-consuming. While government-owned shipyards deal only with repair, they draw supplies, equipment and personnel from the same sources as the private yards. The competition for resources between the government-owned shipyards and the private yards increases the cost of naval construction.

The decline in the shipbuilding industry that is currently being felt has caused skilled workers to seek employment in other fields. There has also been a decline in the industrial support base of vendors who provide shipbuilders with systems and components. These systems and components account for more than 50% of a Naval vessel's cost, and in many cases are currently coming from a single source. In this case the lack of competition from suppliers of critical components increases the cost of naval construction.

This reduction in industrial capacity comes at a particularly inopportune time as the Navy undertakes a significant shipbuilding program (see Table I) [Ref. 3: pp. 15]. The Navy plans to authorize construction of 133 ships between 1983 and 1987 (compare this to the 76 ships ordered from 1977 to 1981). Considering the current state of the shipbuilding industry, this order is going to create some problems. Project this new construction into the fleet a few years--the government-owned shipyards are going to have a problem in the repair and overhaul of all these ships. It

TABLE I

Proposed Five-Year Naval Shipbuilding Plan

NEW CONSTRUCTION	NUMBER	PERCENT
Strategic Ships		37
Trident Fleet Ballistic Missile Submarine	6	
Nuclear Aircraft Carrier (CVN)	2	
Nuclear Attack Submarine (SSN-688)	17	
Guided Missile Cruiser (CG-47)	17	
Guided Missile Destroyer (DDGX)	4	
Nuclear Guided Missile Cruiser (CGN-42)	1	
Destroyer (DD-963)	3	
Total	50	
All Others		63
Landing Ship Dock (LSD-41)	8	
Amphibious Assault Ship (LHD-1)	2	
Guided Missile Frigate (FFG-7)	12	
Mine Countermeasures Ship (MCM)	13	
Coastal Mine Sweeper Ship (MSH-1)	11	
Destroyer Tender (AD)	2	
Fleet Oiler (TAO)	18	
Ocean Surveillance Ship (AGOS)	6	
Ammunition Ship (AE)	4	
Cable Laying and Repair Ship (TARC)	1	
Salvage Ship (ARS)	2	
Fast Combat Support Ship (AOE)	4	
Total	83	
Conversion/Acquisitions/Reactivation		
Aircraft Carrier (CV Slep)	3	
Battleship (BB) (React)	3	
Ocean Survey Ship (TAGS) (Conv)	2	
Range Instrumentation Ship (TAGM) (Conv)	1	
Hospital Ship (TAHX) (C) (Acq)	2	
Fast Logistics Support Ship (TAKRX)	4	
FBM Resupply Ship (TAK) (FBM) (C)	1	
Total	16	

SOURCE: U.S. Department of Defense, 1982. Annual Report on the Status of Shipbuilding and Ship Repair Industry of the United States. Washington, D.C. Table 1-6.

was these types of problems that caused the industry to begin locking for cheaper, faster and less labor-intensive ways to build high-quality ships. The technology that seems to offer the most potential to do those things is CAD/CAM.

C. CURRENT TECHNOLOGY & SHIPBUILDING

CAD/CAM is not new to the shipyards. The next chapter will detail its history, but as a preview relevant to this discussion, CAD/CAM has been in the shipyards about 10 years. U.S. shipyard use of CAD/CAM in the mid-seventies consisted primarily of automated two-dimensional drafting and numerical control (NC) of machining operations. Unfortunately today, ten years later, CAD/CAM use in the shipyards is still at about that same level. The project manager for an extensive survey of CAD/CAM development in shipbuilding states "at the present stage of CAD/CAM development in shipbuilding, computerization tends to be wastefully fragmented. The design department might have a CAD system, production a system for analysis, and manufacturing some NC equipment. Nobody's talking to anybody else, the computer systems don't interact, whereas they could really benefit from passing data back and forth via something like an IGES (International Graphics Exchange System) translator" [Ref. 4: pp. 13]. The commercial shipyards are behind in their utilization of present CAD/CAM technology. However, the government-owned shipyards are even farther behind. This will be discussed in the next section.

D. U.S. NAVAL SHIPYARDS & CURRENT TECHNOLOGY

The Naval shipyards have had CAM, comprised of numerical control equipment, for some time. However, only recently has any CAD capability become available. The Navy yards were able to acquire the Computervision CADDS 4 Designer V

CAD/CAM Systems with the stipulation that they (the shipyards) report the actual benefits derived from the system by March, 1984. This system is referred to as the Interim CAD/CAM System. An example of a typical system configuration is shown in Figure 1.1.

The requirement tc document the actual benefits derived from the system is part of the motivation behind this thesis. Detailed discussion of the requirement and the other motivations are in Chapter 4. Chapters 5 and 6 deal with a methodology designed to identify and analyze the benefits of CAD/CAM to the Navy. A major drawback to that effort is the short period of time some of the shipyards have had the systems and the predominant use of the systems for design and drafting. Although cost-effective in those areas alone, the system has capabilities for integrating CAD and CAM which are currently not being used. The concept of integrating design, manufacture and maintenance activities from a ccmmon database will be explored in Chapter 3.

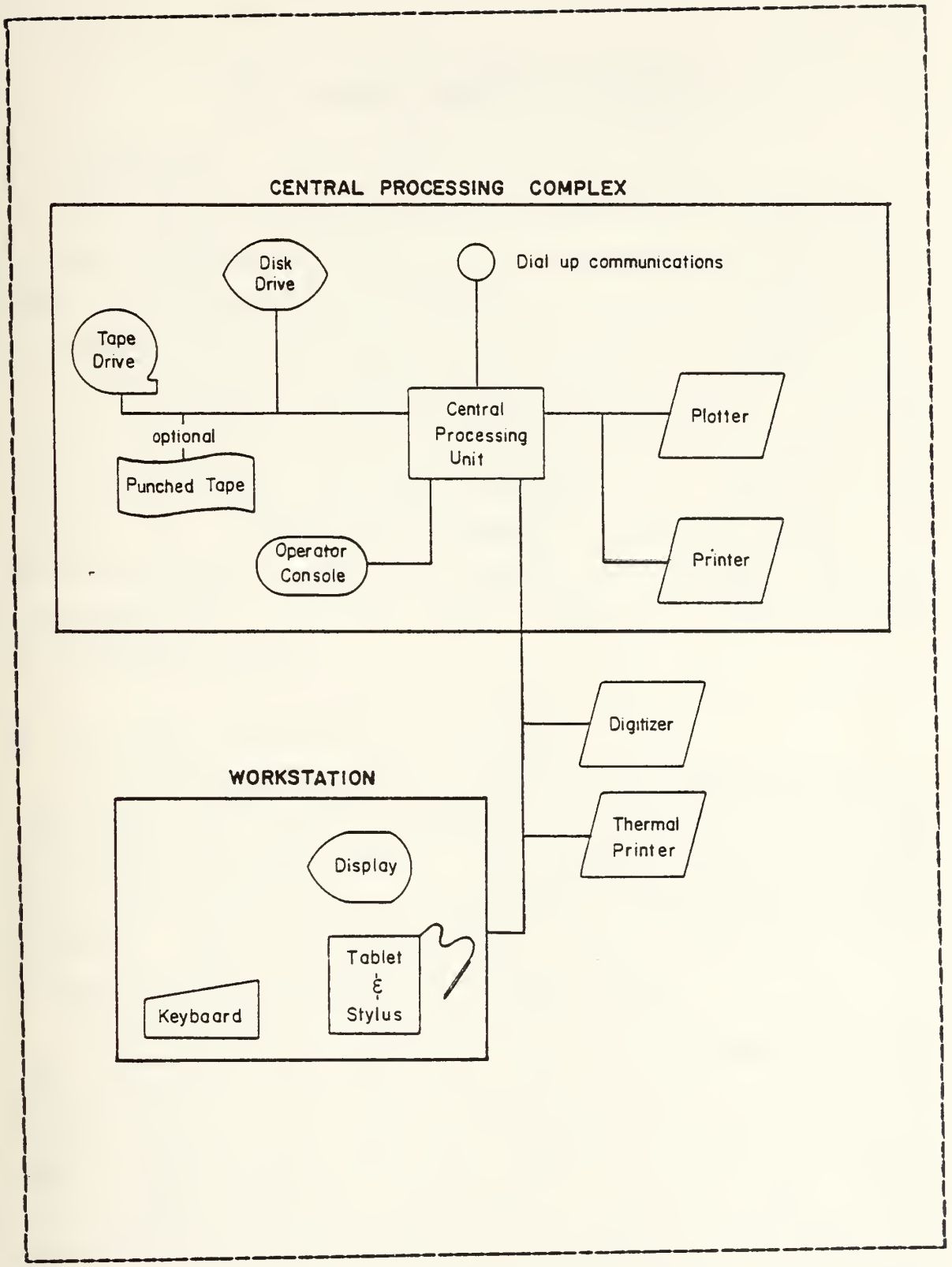

Figure 1.1 Typical Interim CAD/CAM System Configuration

II. A BRIEF HISTORY OF CAD/CAM

A. BACKGROUND

This chapter will provide a historical perspective of CAD/CAM and computer technology, highlighting events pertinent to the shipbuilding industry. This is not meant as an exhaustive history of computer technology or of CAD/CAM. It is intended as background for the reader, in order for him or her to become familiar with the concepts of the technology and its application in the shipyard environment. The history is traced under six headings: 1) Computer technology, 2) Interactive computer graphics (IACG), 3) Numerical control (NC), 4) Computer-aided design (CAD), 5) Computer-aided lofting (CAL) and 6) Computer-aided manufacturing (CAM).

B. THE FIRST GENERATION OF CAD/CAM

In my opinion, the first generation of CAD/CAM begins in 1801 when the Frenchman Jacquard invented the first automated manufacturing system. The Jacquard Loom was a punched card driven device that automatically controlled the weaving process. This was a forerunner of the numerical control process using punched paper or mylar tapes.

In 1830 the first computer was invented by Babbage. The term "computer" had not been coined and Babbage's calculating machine was called an "analytical engine." One hundred years later, the first analog computer was built by Bush. The tempo increased in computer technology with the first digital computer, Colossus I, built in 1943. Three years later, the University of Pennsylvania built ENIAC, and five years after that, the UNIVAC I was built. In computer

Year	Computer	IACG	NC	CAD	CAL	CAM
1801			Jacquard Automated Loom using punched cards			
1830	Babbage Analytical Engine					
1930	Bush builds first analog machine					
1943	COLOSSUS I first digital computer.					
1946	U. of Penn. builds ENIAC					
1951	UNIVAC I 1st Generation					
1952			Parson & MIT develop 3 axis NC using punched cards			
1954			Introduction of NC machine tools in U.S.			Introduction of ASCII
1959			BOC installs 1st NC flame burner in U.K. shipyard	Various shipyards and research groups develop design calculation programs		EAGLE Planning System developed for BOC

Figure 2.1 The First Generation

technology, this is the accepted beginning of the first generation. I have backed the beginning up to include the Jacquard Loom because it is the beginning of programmed manufacturing control. This generation is shown schematically in Figure 2.1 [Ref. 5: pp. 14].

The first generation continued through the early 50's with the large vacumn tube computers being used for accounting tasks. This was the first introduction of computers into the shipbuilding industry. By the mid 50's, many shipyards in a number of countries were using computers for "calculations for hydrostatics, stability curves and capacities" [Ref. 5: pp. 3]. The first change in programmed manufacturing since Jacquard came in 1952, when

Parson and MIT developed a 3 axis numerical control machine using punched cards. It would be two years before NC machine tools were introduced in the United States. Programming these machines was done manually in the basic machine language. In 1959, a group of Scottish shipbuilders formed the Clyde Shipbuilders Computer Group to develop computer applications to shipbulding. This was the first organized effort in shipbuilding to utilize the burgeoning technology.

This is where I mark the end of the first generation of CAD/CAM. The second generation begins with the use of transistors, which increased the computing power 10-fold.

C. THE SECOND GENERATION OF CAD/CAM

The second generation of CAD/CAM, in my opinion, is coincident with the accepted second generation of computer technology and is marked by the replacement of vacumn tubes with transistors, circa 1964. With the increase in computing power it would be only two years until Sutherland developed "Sketchpad," the first interactive computer graphics system. During this period, the Norwegians developed ESSI and IBM completed ADAPT, both pioneering systems in CAM.

The ensuing 6 years can generally be described by the explosion of interactive computer graphics and a flurry of activity in the search for new applications. One such area was computer-aided drafting, and with drafting came computer-aided design (in an interactive graphics sense). What should be apparent is the lack of continuity between numerical control, CAD, and CAM development (see Figure 2.2) [Ref. 5: pp. 4]. Each area was developing on its own. NC proceeded to improve and be more widely used after the creation in 1964 of APT, a higher level numerical control

Year	Computer	IACG	NC	CAD	CAL	CAM
1961	Development of 2nd Gen. computers, transistors replace tubes					ESSI developed in Norway
1963		Sutherland develops SKETCHPAD				IBM completes ADAPT System
1964		CDC introduces DIGIGRAPHIC GM announces their IACG developments				
1965	Development of 3rd Gen. computers, miniture integrated circuits increase computing power by 100	IBM ALPINE System with 2250 scope for GM system Lockheed Georgia develop NC parts programming IACG	NC flame burners installed: Port Weller Puget Sound NS Beth. Steel		AUTOKON introduced to international shipyards	
1966		Lockheed decides to develop its own IACG system			STEERBEAR comp. HIZAC completed	
1967			NC frame bender installed in U.K. shipyard		VIKING comp.	
1968				CASDOS comp.	ASTER comp. BRITSHIP comp.	

Figure 2.2 The Second Generation

language. Also, about that time, another application was found in the shipyards, the generation of NC data through computer-aided lofting (CAL). CAL involves the automated layout of plate patterns and the conversion of these layouts to flame-cutter paths described numerically. The AUTOKON system was the first CAL system and was introduced in 1965.

D. THE THIRD GENERATION OF CAD/CAM

It is difficult to establish the exact timing of the third generation in CAD/CAM. If we look at shipbuilding it would appear to be around 1968 when two significant computer-aided design systems were developed: one being CASDOS, the other being FORAN (see Figure 2.3)

Year	Computer	IACG	NC	CAD	CAL	CAM
1969	Minicomputers developed	COMPUTERVISION offers IACG system	NC flame burner installed at Avondale	FORAN comp.		
1972		Lockheed Georgia dev. COGAP for NAV-SEC			AUTOKON 71 available in United States	
				Newport News lic. AUTOKON		
1973		CADAM marketed by IBM			MarAd purchases AUTOKON for US shipyards	
1977			BIW installs DNC burning MC			
1978		CADAM installed at Avondale		AUTOKON 79 utilizing IACG for part gen. and nesting, offered to US licencees		
1979	Microcomputers developed				CADAM and SPADES interface completed by Avondale	
1981		CADAM installed at NASSCO		BRITSHIP 2 implemented in UK shipyard using CADAM as IACG system		
1982		CADAM installed at Newport News LSCC, Peterson & J J Henry		MEDUSA and SPADES interface completed at Tacoma Boat		
				FORAN 10 offered to world wide shipyards		

Figure 2.3 The Third Generation

[Ref. 5: pp. 4]. The problem arises when one considers that the automotive industry, specifically General Motors, had been secretly involved in CAD since 1959. As mentioned earlier, the aircraft industry was also involved in CAD/CAM with their development of both MCAUTO by McDonnel Douglas and CADAM by Lockheed during the late 50's and early 60's. CASDOS was the U.S. Navy's "Computer-Aided Structural Detailing of Ships" program. It was orginally intended to bring together CAD and NC. It was stated that "the successful culmination of this project (CASDOS) will result in a means for producing fully detailed working plans and numerical control programs for the automatic flame cutting of plates directly by computer using contract plans and detailed specifications as starting input" [Ref. 5: pp. 6]. Unfortunately, the project failed due to "the lack of an

integrated fairing program and a fully developed lofting and NC output capability" [Ref. 5: pp. 6]. At this time, however, a system was developed in Spain called FORAN. The FORAN goal was to provide a CAD system which would develop the contract and detailed design data, and then provide the working drawings to produce the ship. Later extensions of FORAN involved CAL and CAM.

During this generation mini-computers were developed, networking between mini's and mainframes grew, and CAD and CAM began to come together. Characteristic of the generation were automated numerical control tape generation, and CAD with on-line engineering analysis and real-time simulation. Currently at the end of the generation, (around 1983), computer technology has advanced to even smaller and faster computers. CAD/CAM is a way of life in the automotive and aircraft industries and is well established overseas in shipbuilding with FORAN, BRITSHIP 2, and AUTOKON 79. Unfortunately, U.S. shipbuilding failed as an industry to take full advantage of the technology. The next chapter will define my view of the next generation and beyond in CAD/CAM.

III. CIDMM, THE NEXT GENERATION

A. INTEGRATION OF DESIGN, MANUFACTURING AND MAINTENANCE

The next generation in CAD/CAM is beginning now. The significant difference between this and the previous generation is not due to hardware breakthroughs or new applications, but is due to an attitude change. The attitude that is changing is the belief by those using the technology, that only through total integration of CAD and CAM can the real potential of the technology be realized. Previously CAD and CAM had been thought of as separate activities. A number of terms have been coined describing this integrated approach to design and manufacture. Computer-Aided Engineering (CAE) and Advanced Integrated CAD/CAM are two such terms.

I would like to go one step further in the conceptualization of what I think this generation holds for CAD/CAM by adding maintenance to the integrated design and manufacturing concept. The addition of maintenance considerations in the process closes the loop between designer, manufacturer and user. The term I have chosen to describe this concept is both simple and symbolic--CIDMM; Computer Integrated Design, Manufacture, and Maintenance. It is symbolic in the removal of the "/" between CAD and CAM, thus emphatically stating there cannot be any barrier between design and manufacture. The characteristics of CIDMM will be described in terms of the shipbuilding industry but applicability to other industries should be easy to extrapolate.

The first realization that must occur is that "we are no longer preparing drawings, we are building the prototype in

the ccmputer" [Ref. 5: pp. 19]. This has, in my opinion, been the biggest stumbling block to the successful implementation of CAD/CAM in the shipbuilding industry. CIDMM goes one step farther and rather than building the prototype, we are building each individual ship in the computer. A description of what exactly is involved in CIDMM is in crder. Figure 3.1 shows the present manual approach to the creation and passing of the engineering and administrative information. All the information is passed via a paper medium, which is bulky, hard to revise and typically out of date. The repositories handle the information via aperture cards and microfilm on a system similiar to one the Air Force has labled "archaic" [Ref. 6]. Figure 3.2 shows the creation and passing of the engineering and administrative information via three digital data bases. These digital data bases allow almost real-time transfer of information providing disseminatien of the most up-to-date information and rapid feedback from the fleet user. Incorporating changes to cr transfering information from a digitized data base is simple and fast. There is no need to redraw drawings everytime a change is made or a drawing is transferred. There is no need to wait years for changes to be incorporated in the technical documentation. There is no need for the repositories to keep millions of aperture cards, each representing 1 or 2 drawings on file. A single 10 inch video disk can hold approximately 6000 E size (36" x 48") drawings at a cost of about $3.00.

Future miniaturization in laser disk technology will provide the seaman on the ship with the ability to take a small video disk and player to the piece of machinery he is working on and view his entire maintenance task, (including troubleshooting, disassembly, repair and assembly) at the maintenance site. An additional advantage to the video disk medium is its ambivalence to electromagnetic interference.

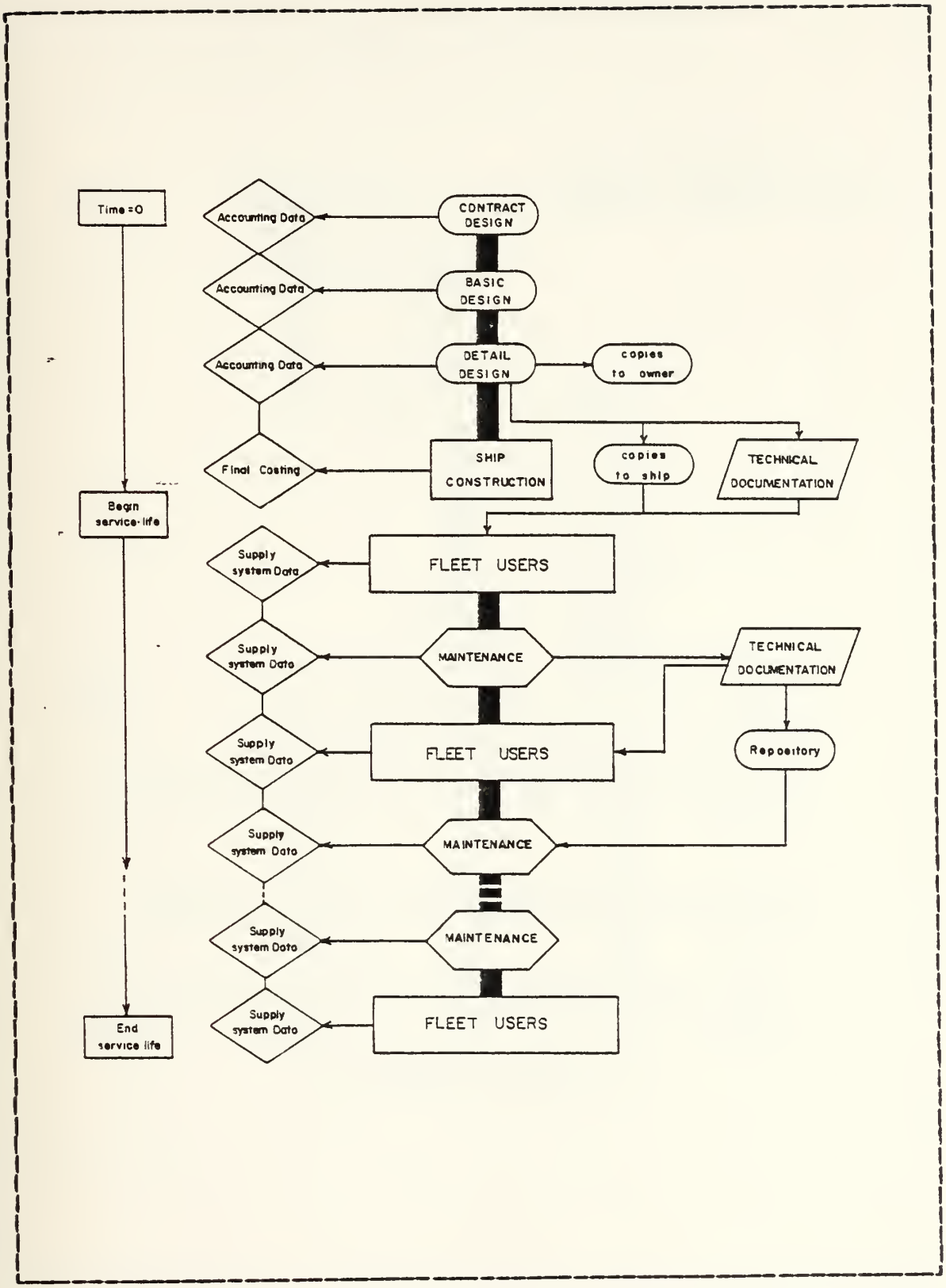

Figure 3.1 Manual Approach

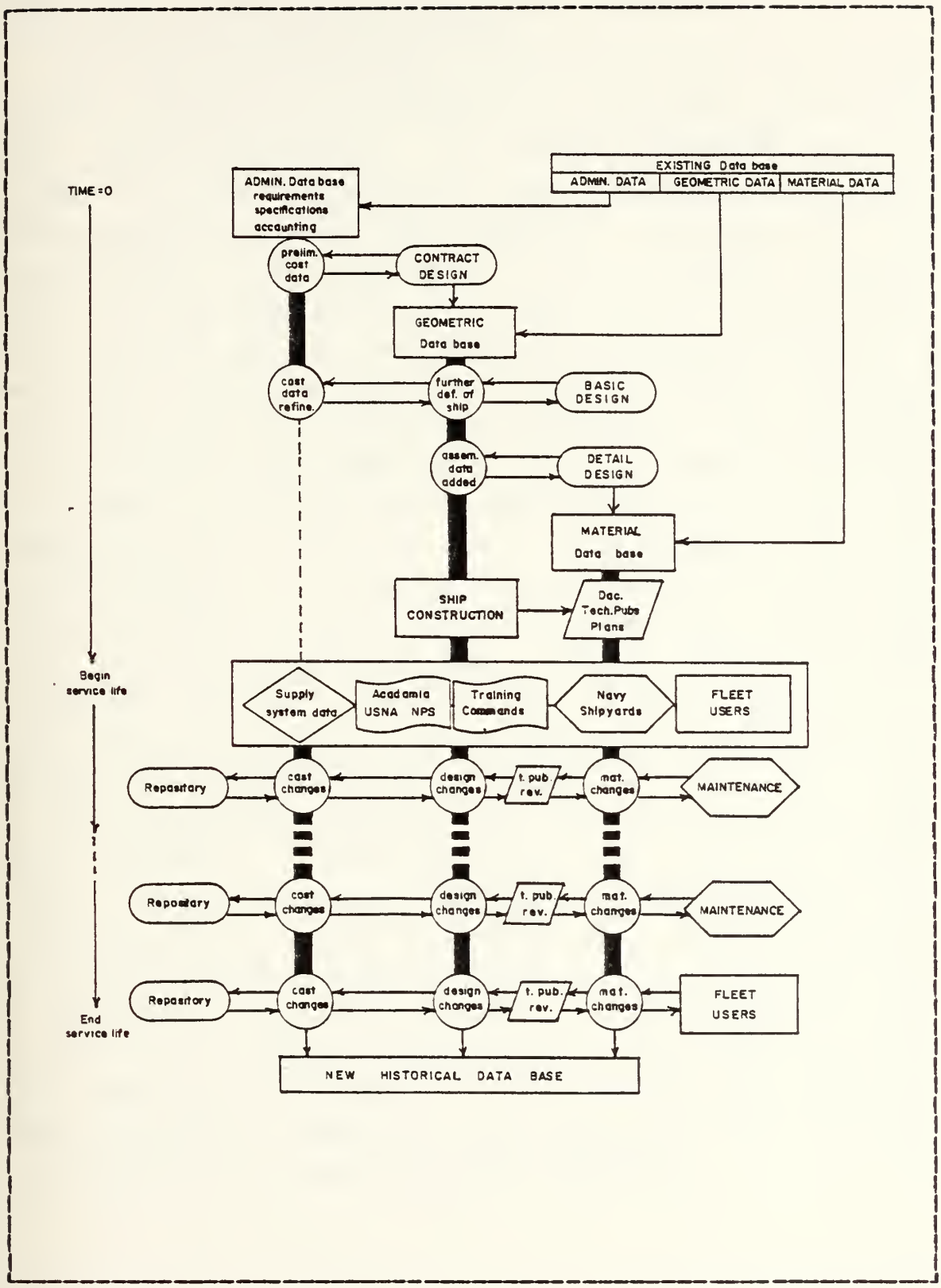

Figure 3.2 CIDMM Approach

This could be quite important in the various electromagnetic fields found aboard naval vessels.

This level of involvement of the user with the detailed figures created by the designer is a fundamental improvement from today's technology. In between the user and the designer is the manufacturer. The existence of a common engineering data base (the geometric data base and the material data base) allows the direct transfer of design data to the manufacturer on the shop floor. Direct numerical control (DNC) is a manufacturing technique currently in use in the aerospace industry. Direct transfer eliminates the entire step of interpreting the drawings and programming the numerical control machine. Direct transfer allows all the pieces to be fabricated from the design, not various intrepretations of it, resulting in a product that fits together better. In shipbuilding, the bringing of subassemblies together is called zone construction. "Ships are built in chunks around the yard. These modules are built completely outfitted and ready for launch. When all is ready they are brought together swiftly on the (ship) ways, welded into a complete ship and launched. Not only is time on the ways greatly reduced, but construction is considerably simplified. Crews can get at their work more easily, there is more space for manuvering equipment around the isolated modules, more bottlenecks are largely eliminated and delays do not accumulate" [Ref. 4: pp. 14]. This would be impossible if all the pieces to "the puzzle" were not created from a common engineering data base. This construction technique was pioneered by the Norwegians and has since been successfully adopted by the Japanese. Both countries are leaders in the use of CAD/CAM technology.

B. SHIPBUILDING, CIDMM, AND THE FUTURE

So far, this discussion has not been exceptionally futuristic. Most of the concepts are implementable with today's technology. With some imagination one can envision complete design and manufacturing systems built around a common data base. A designer would sit in an easy chair (perhaps with a head mounted cursor control mechanism) and select from a menu the type of ship he wanted to design. Once selection was made, a generic ship of the type selected would appear. Through the designers inputs of size, speed, cost and other parameters the system would develop the design automatically, much as group technology and generic part definition is done today. The system should have the ability to interact with the designer, capitalizing on the designer's imagination, skill, and the systems ability to optimize or automatically design. (This type of symbiotic man-machine relationship has been a dream for many years. Advances in artificial intelligence are making it closer to being a reality, but, unfortunately, it is still a long way off.)

Once the designer is satisfied with the design, a command would generate the detailed information, parts lists, cost estimation, and production schedule. Another command would transfer the design to an automated shipyard where intelligent robots would select the raw materials and begin machining the parts from the production schedule previously generated. As the parts were produced they would be automatically assembled. These assemblies and the components from subcontractors would be pieced together until the final ship was complete.

While the construction process was going on, the same data would be used to program maintenance "manuals" in the form of video disks or some other medium. Automatic authoring, a concept being explored today by the Navy, would

provide the text, while the detail designs would provide the "figures," figures in the sense of 3-dimensional color graphic images.

It appears in this shipyard of the future that the human element has been removed. Although possible, this would be a tremendous mistake. The human element should be removed from the mundane, time-consuming, or dangerous tasks where a robot could perform them better, and placed in those positions where humans will always be needed, positions that require thought, judgement, and intuition.

The U.S. is a leader in computer technology. However, the country has fallen behind in its industrial application of that technology, especially in the shipbuilding industry. The U.S. Navy as the predominant customer of U.S. shipbulding is in a unique position to influence its direction and growth. By pursuing the CIDMM concept, the Navy can not only improve itself but can improve this country's productivity and the technological edge that will guarantee the lifestyle enjoyed in this country today.

IV. DISCUSSION OF EXISTING BENEFIT METHODOLOGIES

A. OVERVIEW

A historical background and futuristic projection of the CIDMM technology has been presented in the previous chapters. I hope the case has been made for the Navy becoming a leader in this technology. Accomplishing this will require a very large investment in manpower and capital resources. Part of this investment has already been made with the procurement of the interim CAD equipment currently in place at the eight Naval Shipyards. Along with the authorization [Ref. 7: pp. 2] to begin investigating the technology as it applies to the shipyards, was a requirement of the Naval Sea Systems Command to:

> "submit an evaluation showing the actual observed productivity increase attributable to CAD/CAM. This report will serve to verify the economic analysis in the SDP and to provide a basis for projections for the long range plan."

This requirement, combined with the requirements of SECNAV Instruction 7000.14B which calls for economic analysis on major programs (part of which should consist of benefit analysis) [Ref. 8], and the lack of existing benefit analysis methodologies in the field is the motivation for the remainder of this thesis. Existing methodologies will be discussed followed by the development of a new methodology, "the Grahlman methodology." The Grahlman methodology will draw from the existing methodologies' strengths, be applicable to Interim CAD/CAM Systems installed at the shipyards, and, more importantly, will be extendable to the CIDMM concept discussed in the first portion of this thesis.

B. EXISTING BENEFIT ANALYSIS METHODOLOGIES

Previous benefit analysis has been primarily limited to CAD systems. Most of the methods currently published attempt to quantify the tangible benefits, usually man-hour savings, compare those (converted to dollar savings) to the costs of the system, resulting in a sort of net gain assessment. A negative net gain indicates a loss. The intangible benefits, such as improvements in drawing quality or design innovation, are given a cursory discussion and then ignored, resulting in a "worst case" type of analysis. Four methods will be reviewed. Two deal with purely tangible benefits and two attempt to measure CAD productivity wholely through subjective analytical techniques.

In reviewing another's work, it must be kept in mind that the reviewer's perspective is considerably different than that of the author. The reviewer also does not share the luxury of detailed derivation to aid comprehension. Generally he must extract the essence of a piece of work as it applies to his use, which seldom does the original work justice. With that caveat in mind, we will proceed.

1. Chasen's Method (as applied by Long Beach N.S.)

Sylvan Chasen's methodology for determining "the break-even point for interactive graphics cost savings versus the cost of capital equipment and labor charges" was used by the Long Beach Naval Shipyard to justify acquiring additional CAD/CAM equipment [Ref. 9] under the Computer Aided Engineering and Documentation System (CAEDOS) contract no. 00123-81-R-0456. The methodology was extracted from Chasen's paper "Formulation of System Cost Effectiveness" [Ref. 10: pp. 263]. This discussion will use the model as presented in the paper.

The model is

$$\frac{C.R.}{H3 \cdot Rm} = \frac{K}{H3 \cdot Rm} + \frac{H1 - H2}{H3} - \frac{Rm + Rc}{Rm} \qquad \text{(eqn 4.1)}$$

where

C.R.=Cost reduction in dollars,

H1=Man-hours for any defined task, set of tasks, or project prior to introduction of CAD/CAM,

H2=Man-hours on the same basis as H1 except that they are the hours unaffected by CAD/CAM. H2 is a subset of H1,

H3=Man-hours spent at the CAD/CAM console to produce the same amount of work previously done in (H1-H2) hours,

Rm=Average man-hour rate (console user) in dollars/hour,

Rc=Console rate in dollars/hour, and

K=Estimated dollar savings attributable to the non-direct (intangible) benefits.

Long Beach N.S. chose to use the model in a worst case scenario by giving no credit to intangible benefits (K). This approach has merit in that measuring or even estimating the intangible benefits of CAD/CAM in terms of man-hour savings or dollar savings can be very difficult. These benefits and their associated problems will be discussed later. However, note that by giving no credit to the intangible benefits, i.e., setting K=0, an additive term is dropped from the equation, resulting in the most conservative estimate of savings. If the cost reduction (C.R.) is also set to zero (the threshold level) [Ref. 10: pp. 268] the only remaining terms are the productivity ratio (P.R.) defined by [H1-H2]/H3 and the "maximum" productivity ratio (Rmax) defined by [Rm+Rc]/Rm, which are equal at the break-even point. This establishes a cost effectiveness criteria.

For the CAD/CAM system to be cost effective P.R. must exceed Rmax.

Significant in Chasen's discussion on productivity [Ref. 10: pp. 261] is his H1-H2 term that appears to be the first explicit correction of the common practice in CAD/CAM productivity measurement of simply taking the difference in the time required to do a task manually and the time required to do the task with CAD/CAM. This direct comparison of total task, set of tasks, or project times is in error because it includes administrative time not influenced by CAD/CAM, which, if included in the difference calculation, would result in erroneously lower productivity ratios.

Only two topics are not adequately addressed with the method--the first being how the man-hours H1 and H2 should be determined. Is H1 to be determined by historical records? Is it to be estimated? Is H2 measured, and if so, how? Task analysis techniques exist which could accurately determine these but are costly in terms of time and money. The second topic not adequately discussed is the notion of operator skill level on the system. Chasen admits the productivity ratio (P.R.) "is dependent on such things as the skill level and quality of work and the characteristics of the CAD/CAM system" [Ref. 10: pp. 262]. Implicit are the assumptions that all the operators are at 100% efficiency, or that the man-hours spent at the console produce the same amount of work. The variable (H3) represents some constant average of user skill levels, and is the same as the skill level of those engaged in doing the task prior to CAD/CAM. In the long run this may be true, but when one considers the normal technological life of most computer systems of about 8 yrs [Ref. 11: pp. C.2-5], this long-run argument falls short.

2. Shah & Yan's Method

R. Shah and G. Yan presented a paper [Ref. 12: pp. 16] at the 15th Design Automation Conference which proposed a simple method of assessing the net gain achieved from CADDS[1] in a drafting office environment. Their method uses the simple relationship:

Benefits (B) - Costs (C) = Net Gain (G)

Benefits are further subdivided by subscript into drawing "types."

Their benefit model is:

$$B_{T_i} = N_i \left[S_{M_i} - \left(\frac{S_{S_i}}{E} \right) \right] \qquad \text{(eqn 4.2)}$$

with

$$N_i = \left[n \cdot w \cdot H \cdot f_i \cdot A \cdot \left(\frac{E}{S_{S_i}} \right) \right] \qquad \text{(eqn 4.3)}$$

---

[1]CADDS is defined in this paper to be commercially available, stand alone, multiple-station computer-aided design and drafting systems.

which combine to yield

$$B_{T_i} = [n \cdot w \cdot H] \cdot f_i \cdot A \cdot \left[\frac{S_{M_i}}{\left(\frac{S_{S_i}}{E}\right)} - 1 \right] \qquad \text{(eqn 4.4)}$$

where

B_{T_i} =The time benefit (savings) in man-hours of a CAT. i drawing,

N_i =Average number of CAT. i drawings produced/period,

S_{M_i} =Average man-hours required for drafting a CAT. i drawing manually,[2]

S_{S_i} =Average man-hours required for a CAT. i drawing using CADDS,[3]

E=CADDS user efficiency factor, ($0 \leq E \leq 1$)

n=Number of work stations,

w=Number of shift hours/period,

H=Single shift hours/period,

f_i =Fraction of CADD alloted to CAT. i drawings, and

A=CADDS system availability.

First, consider the way Shah and Yan deal with the question of "tasks not affected by CAD/CAM." In the derivation [Ref. 12: pp. 21] Shah and Yan include two terms, which represent the average man-hours needed for planning, preparation approval, issue, and distribution of Category i drawings produced on CADDS or manual methods respectively. They conclude that "based on our experience, activities like planning, preparation, approval, issue and distribution take similar man-power effort whether the task is done manually or using CADDS." This allows them to equate the two terms, and, because of their algebraic relationship, drop them from

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[2]Includes extracting data for wiring lists, etc., where applicable.

[3]Ibid

the equation. The result is a comparison only of tasks "affected by CADDS," similiar to Chasen's comparison.

This model is also "worst case," in that intangible benefits are ignored. Shah and Yan do include an efficiency term (E) that adjusts the man-hours expended by a user that may be new to the system and hence not as productive as he could be, to that of someone who is considered to be 100% efficient. A vendor should be able to provide accurate learning curves on a given system for determination of this term.

3. CAEDOS Productivity Measurement Method

The next method differs significantly from the previous two in that it deals with productivity in a subjective, instead of quantitative, way. The method was presented in a tentative work plan [Ref. 13] for the CAEDOS productivity study to be conducted by a private consulting firm under contract to the Navy. The "productivity measurement plan" details a measure of productivity (MP) that consists of a weighted sum of productivity factors:

$$MP = \sum_{i=1}^{M} W_i \cdot PR_i \qquad \text{(eqn 4.5)}$$

where

PR_i = Improvement in productivity due to a particular factor i of computer-aided engineering,

W_i = Weighting of factor i's impact on productivity, and

M = Total number of productivity factors.

The productivity factors identified in the CAEDOS study include:

1) Time
2) Reproducibility
3) Skill levels
4) Communication
5) Configuration mgmt.
6) Cost & value of information
7) Quality
8) Automization
9) Documentation
10) Improved project & resource management
11) Reduction of uncertainity
12) Ability to spot unsuccessful projects early

A measure of cost (MC) is then determined by summing the costs in obtaining certain features (factors):

$$MC = \sum_{i=1}^{M} C_i \qquad \text{(eqn 4.6)}$$

These two terms are then combined in a productivity/cost ratio (PCR):

$$PCR = \frac{MP}{MC} \qquad \text{(eqn 4.7)}$$

The strength of the proposed measure lies in its simplicity. The measure of productivity (MP) is easy to explain and represents a "common sense" approach to the problem of productivity measurement; however, this technique is better suited for measurement of completely non-quantifiable entities, such as "the value of learning" because of the difficulties in defining a universally accepted measure of value. With a weighted sum model, a measure of value is determined by a weighted average of someone's, or some group's subjective assesment of value.

A major weakness of the model as it applies to Department of the Navy Productivity Measurement is the completely subjective measurement of factor 1, time. SECNAV Instruction 7000.14B clearly states "output measures (benefits) shall be expressed quantitatively whenever possible", [Ref. 8: pp. 10]. Time savings represent a major factor in this type of productivity analysis [Ref. 13] and should be measured quantitatively instead of subjectively.

The model has analytical problems. The measures are too subjective for meaningful analysis. Subjective terms should have some sort of sensitivity analysis performed on them to determine if they are unfairly forcing a particular outcome. Also note that in the model subjective weights are multiplied by subjective productivity factors. This multiplicity further confounds the sensitivity analysis. To be adequately analyzed, the reaction of the model to all possible ranges of both factors should be examined.

The model has data collection problems. For example, to reduce the subjectivity in "skill levels," you would have to test all the engineers on their professional skills before they used the CAD/CAM system, then retest them after use. The difference would be a measure of their improved skill level. This assumes the engineers have not used CAD/CAM before, which is unlikely, and further assumes the administration of a representative skill level test, which may not be feasible.

Additional data collection problems occur with the measurement of cost (MC). Each Ci represents a cost of obtaining the productivity of the ith factor. Is this to mean that out of the total system cost one has to carve the cost of those system components that make the factor possible? As an example, consider the factor automization that represents the system's ability to automate certain

design practices like rules checking. A designer, through his experience and education, knows certain basic design rules. The computer system can be programmed to check a design against these rules and flag any discrepancies. The cost asscciated with this ability should, by implication of the model, be the ccst of the software that provided the rules checking ability. The question that now arises is "do we include the cost of the hardware needed to provide the ability"? What if a specific piece of hardware provides two capabilities? Should it be counted twice? It is not completely clear what the measurement of cost really is.

My final point on this model is how easily it could be abused. Any competent analyst could support or refute almost any position with this model by manipulation of the weights, measures of productivity, and measures of cost. There is no auditable data source, only a group of people's opinions that determine if a system is productive, and by how much.

4. Packer and Kahn's Method

The final methodology reviewed probably represents the "state-of-the-art" in CAD productivity measurement. It was developed as part of a two year, multi-firm productivity study which is still in progress at M.I.T. under the direction of Dr. Michael Packer. Their motivation for developing the method was the lack of work in the area. In a paper at the N.C.G.A. Conference, '82 [Ref. 14: pp. 1], Dr. Packer and Adina Guartzman charged "the present state-of-the-art in evaluation of the productivity or effectiveness of CAD systems is abysmal." The three previously reviewed methods represent the only published work in the field discovered in my research and tend to support Packer and Guartzman's charge.

The M.I.T. study has two separate facets: the measurement of tangible benefits and the measurement of intangible and collateral benefits. Packer builds a case against comparing actual CAD time with estimated CAD times [Ref. 15: pp. 52-54]. I disagree with his statement [Ref. 16: pp. 2] that comparing actual CAD times with estimated CAD times is "useless," however. Each situation must be considered individually. In the Naval Shipyards case, there simply is not time to collect the data and analyze it using Packer and Kahn's method before the March 1984 deadline. The other and most important point is "what is the analysis being used for?" For acquistion decisions, appropriate estimates are adequate.

The M.I.T. study is collecting data on "project cycle time" and "changes in the project" other than customer requests. The data is being collected on all jobs, CAD or manual, with the intent of developing a large enough data base to make statistical comparisons. They hope to generate descriptive statistics on:

--Project cycle time
--Job drafting/design time
--Number of changes by source and reason
--Job description parameters (subjective descriptors like complexity, innovativeness, etc.)

The next phase of the analysis involves stepwise regression and analysis of variance to determine the relative effects of a number of variables on actual and estimated job completion times (the independent variables are job description parameters). The same techniques will also be used to look at CAD useage and job parameters on project cycle time, CAD useage and job parameters on the number of errors and changes requested, and last, a determiniation of the distribution of the time of the drafting and design effort per project.

The intangible and collateral benefits are measured by analysis of a detailed questionaire designed to break the broad, vague concepts such as flexibility, into detailed specific criteria of organizational effectiveness. Hierarchical clustering is used to organize the questions into groups. See Table II [Ref. 16: pp. 4] for sample questions and groupings.

Alpha in Table II is the Cronbach measure of reliability. It is used to estimate "the reliability of empirical measurements obtained in one administration of a measurement instrument (questionaire)" [Ref. 17: pp. 57]. Thus, alpha represents a measure of the internal consistency of the questions in the group. "General guidelines for values of alpha in empirical research are that alpha=0.6 is adequate (to establish a group) in exploratory analysis, and that alpha=0.8 is preferred for applied work" [Ref. 17: pp. 158]. As shown by the Table II alpha statistics, three of the five groups meet the 0.6 criteria to establish a group. Beta, in Table II, is the coefficient of generalizability [Ref. 18: pp. 17] and is defined as the ratio of population variance to the variance of the group. It expresses how well the group is likely to place individual questions relative to all other questions. Since the variance of the group will always be less than the variance of the population, beta will be between 0 and 1. The higher beta, the more general the questions in a group.

The groups in Table II were formed by simultaneously maximizing Alpha and Beta. Maximum loading on a cluster means that a specific question had a maximum correlation between it and its corresponding group. Each question is scored between 1 (very difficult) and 7 (very easy). Questions were worded so that higher scores corresponded to higher levels of effectiveness [Ref. 17: pp. 46]. The mean scores of each question in a group are averaged to provide a

TABLE II

Variables in Order of Their Greatest Cluster Loading

GROUP 1: Morale, Feedback, Resources For Work
Alpha=0.88 Beta=0.80

Own morale is high
Good feedback from supervisors and co-workers
Encouraged to learn new skills
Group's morale is good
Do work that you do best
Feel a part of work group
Given chance to develop own special abilities
Often try out new methods
*Can easily tell whether doing good work
Often experiment with changes
Easy for supervisors to evaluate work
Know the quality of work expected of you
Often get advice from people within work group
Have right amount of equipment to do job
Often get advice from people outside work group
Training is adequate

Group 2: Challenges Alpha=0.70 Beta=0.46

Often solve tough problems
Most work is challenging rather than routine
Large amount of skill required to do job
Work rarely requires repetitive tasks

Group 3: Changes Alpha=0.68 Beta=0.62

Ofter do work requiring revisions
Easy to redimension.to change tolerances
Rarely get distracted
Easy to switch from one job to another
Easy to work on scmeone else's drawing

Group 4: Wrapped up, See Results
Alpha=0.56 Beta=0.51

*Have much freedcm of choice in how to get job done
Often find myself "wrapped up in work"
Often find myself "racing along in work"
Easy for me to see results of my work

Group 5: Teamwork Alpha=0.44 Beta=0.31

(Group physically isolated from other workers)
(negative correlation)
Often work on scmeone else's drawing
Rarely work accrding to rules
Often work as part of a team

* Variable did not have maximum loading on this cluster

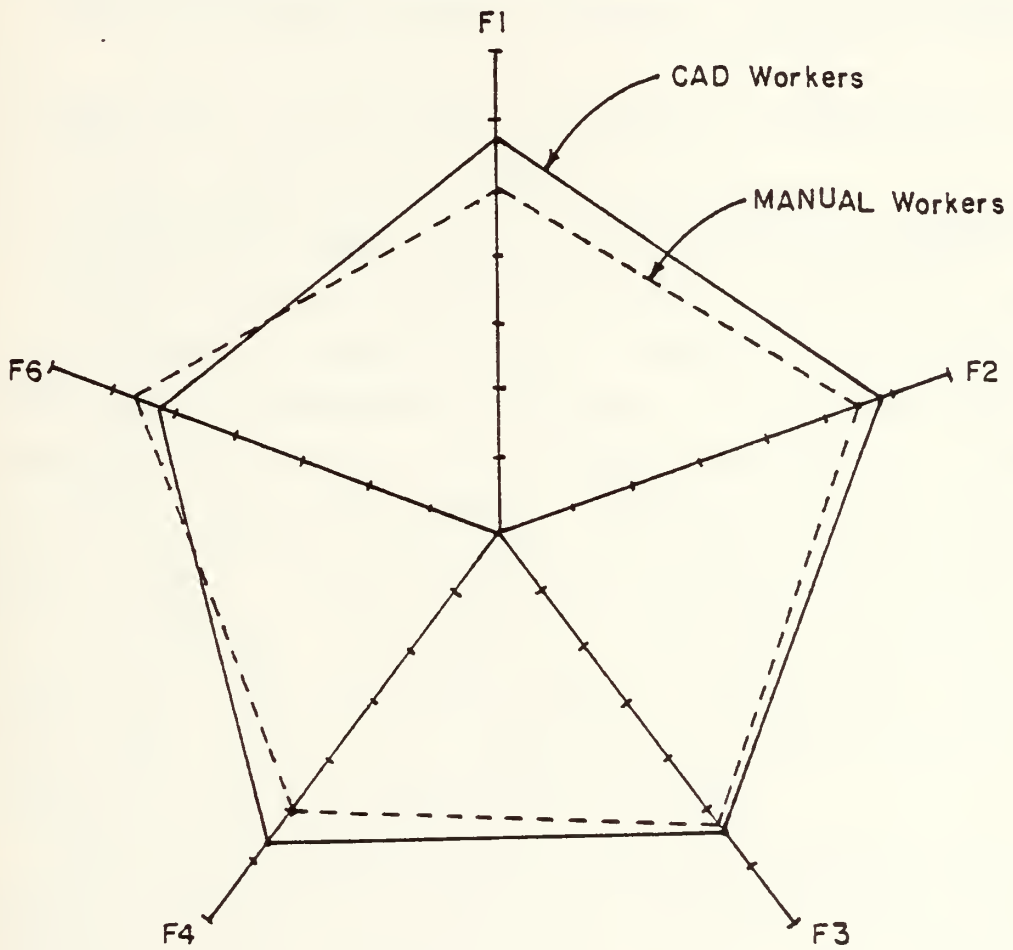
Questions which did not combine with any cluster:

Rarely slowed down by delays not under my control
Often get together with co-workers to do a better job
Personally respcnsible for quality of group's work
Work station has convenient layout
Often lay out a jcb different ways

COMPANY E QI FACTOR GROUP SCORES

(groups suggested by 8-factor solution)

F1 "own creativity"
F2 "group functioning"
F3 "pace , concentration"
F4 "flexibility"
F6 "information , resources"



factors 5,7,8 not used to construct clustered factor groups because of low reliability due to bipolar (+,-) interitem correlations.

CAD n=8 MANUAL n=6

Figure 4.1 Perceptual Map

point estimate for the group. These are plotted on a "perceptual map" resulting in the pentagon-like Figure 4.1. The center is the origin and each group score is plotted out from the center along its respective radial. The further out the radial, the more effective the system. The interconnection of the points gives the pentagon shape, and provides a way of distinguishing the manual points (dashed line) from the CAD points (solid line).

The advantages of this perceptual mapping technique are:

1. The system can be used to monitor performance over time.
2. Abstract concepts are made explicit.
3. Perceptions about the organization by different groups within the organization can be compared.

There are three major drawbacks to the perceptual map for information presentation. The first involves the interconnectivity previously discussed. The interconnection of the radials implies some connection between adjacent radials when in fact none exists. The second involves most people's subconscious preference for aesthetically pleasing geometric shapes. This preference introduces an element of bias. For example, in Figure 4.2 Factory A and Factory B have identical CAD and manual system perceptions, however Factory A will generally be perceived as doing better with CAD because of the more pentagon-like shape.

The third drawback is the lack of indication of the accuracy of the points on the various radials. The standard deviations have been computed [Ref. 17: pp. 75] and should be displayed somehow.

A better presentation of the data might be through a multi-variate box-plot display [Ref. 19: pp.29]. A better comparison of the systems can be made from the additional information presented. Data with the same means and standard deviations as that contained in Figure 4.1 is displayed

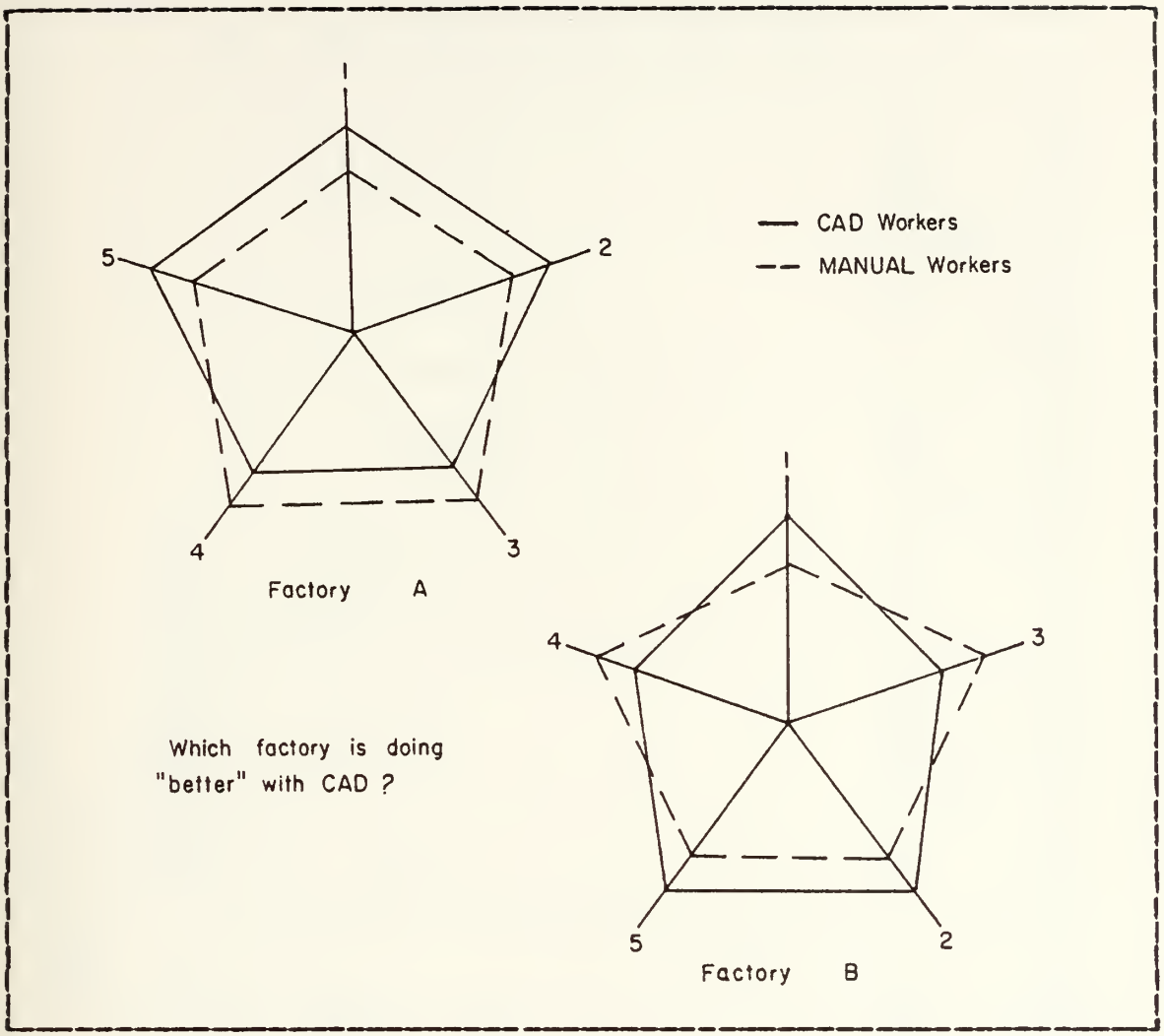


Figure 4.2 Perceptual Differences

with this box-plot method in Figure 4.3. As can be seen, the relative positions of the interquartile ranges gives an indication of whether CAD workers or manual workers are more "productive" in the five areas. Now though, the decision-maker is presented with information about the underlying distribution of the answers, and with this information can immediately decide whether the differences are significant for the decision process. This is not to argue that t-tests for significance should be discarded, they have

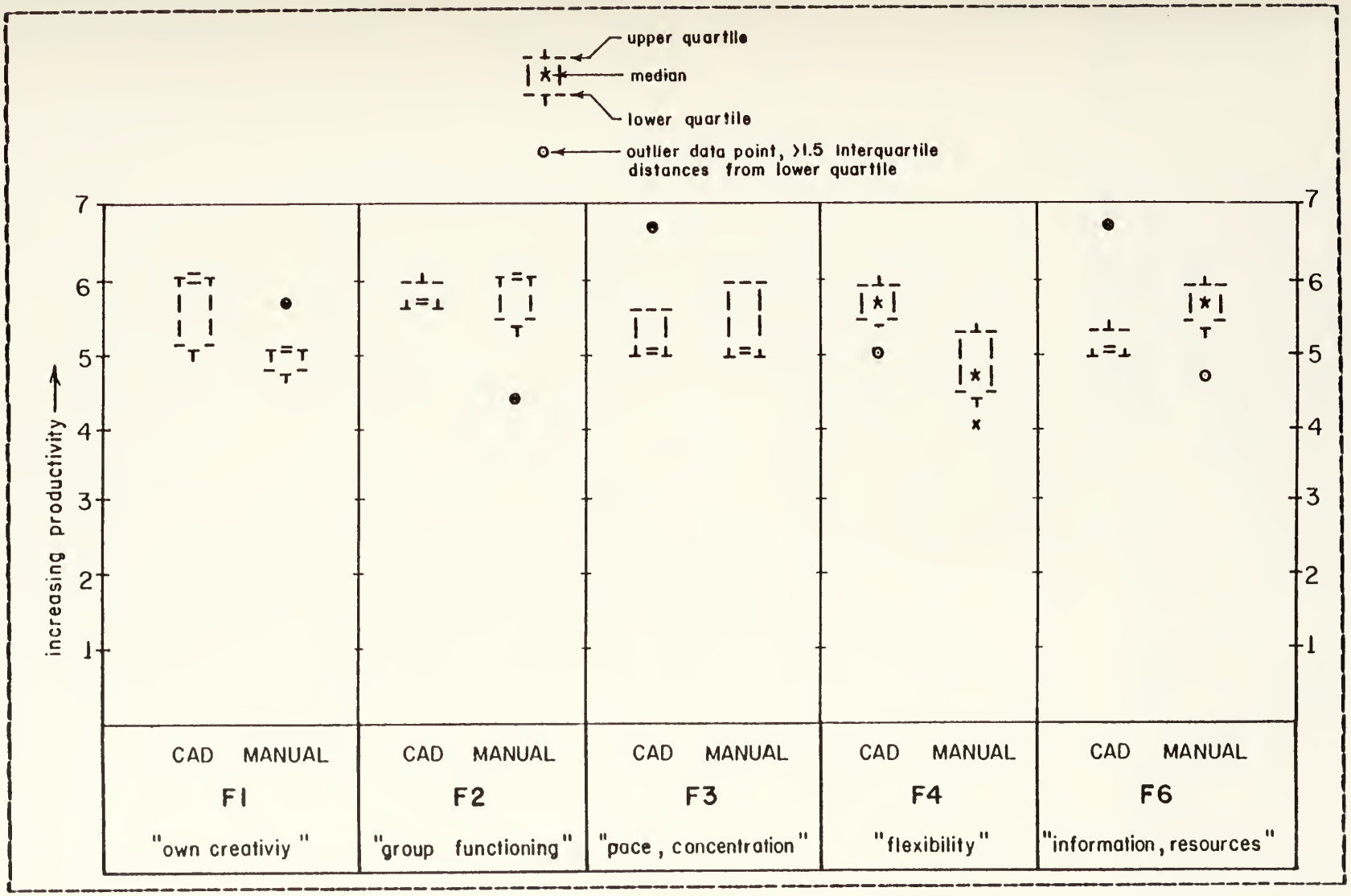


Figure 4.3 System Comparison

their place in the analysis, but to point out that the goal is to produce a decision-aid that is useful to decision makers in comparing differing systems. An additional advantage to this data representation is that it can be computed and plotted automatically. An example of a FORTRAN subroutine used to create similiar box-plot displays can be found in McNeil [Ref. 19: pp. 46].

V. GRAHLMAN'S METHOD

A. MOTIVATION

The four previously discussed methodologies have their own strengths and weaknesses in dealing with the question of "benefits" derived from, or relating to, the use of CAD/CAM (CAD in most cases). Chasen [Ref. 10: pp. 263] identifies the need to compare only "tasks affected by CAD/CAM" for productivity measurement but fails to account for user efficiency on the system. Shah & Yan [Ref. 12: pp. 17] deal with the efficiency problem and provide a very useable methodology for tangible CAD benefit analysis. In 1978 this was farther than anyone else had gone. Unfortunately, today we need a methodology to measure tangible and intangible benefits of CAD/CAM and of the next generation technology, CIDMM. The CAEDOS study [Ref. 13] offers a method to measure the intangibles of CAD/CAM which could be extended to CIDMM, but which has some real problems with data collection and analysis. Packer and Kahn [Ref. 16: pp. 2] offer a methodology that measures both tangible and intangible benefits of present CAD technology. This method would be hard to extend to CIDMM technology because of the tangible benefit measurements requirement to analyze a large enough data base to be statistically significant. The time required to develop that data base could probably be measured in decades. The intangible benefit measurement method, however, does appear quite useful and expandable. Clearly, none of the methods were specifically intended for shipyard analysis and hence are not really adequate. What is needed is a methodology that synthesizes the good points and avoids the pitfalls of the methods discussed--a methodology

specifically tailored to the shipyard environment--such a methodology is proposed here.

A good source of informed discussions of the benefits to be derived from a CAD/CAM system in the shipyard environment is the requests shipyards submit to the Naval Sea Systems Command (PMS-309) for interim CAD/CAM equipment. These requests require the shipyards to justify the acquisition, and usually include a listing of the benefits they hope to enjoy if the system is obtained. Study of these and related requests resulted in the list of benefits found in Table III. Benefit analysis usually involves comparison of some new system to the existing system or the status quo. Table IV lists the relevant benefits of maintaining the manual design, drafting, manufacture and maintenance methods currently in use.

In developing a methodology to assess the benefits of CIDMM as they apply to the shipyards, it is important to keep in mind the purpose of a methodology. The intended use is to objectively quantify, where possible, the relative tangible and intangible benefits between the existing system and a new technology. Presently, that means providing a methodology to analyze the Interim CAD/CAM Systems being installed at the shipyards. The method, however, will still be extendable to analysis of the next generation of systems described by the acronym CIDMM.

Following Packer, the methodology is divided into multiple parts. The first part addresses the tangible or quantifiable benefits of the Interim CAD/CAM System. The second addresses the intangible benefits and the last part addresses those benefits not falling easily into either of the above categories. A formal delineation of the methodology is presented in the next chapter.

TABLE III

Relevant Benefits of CAD/CAM

1. Increased productivity (reduced man-hours to accomplish task) through automation of repetitive time-consuming tasks.
2. Increased productivity through the ability to rapidly produce a design from existing generic element designs.
3. Increased productivity through the ability to rapidly edit existing designs.
4. Increased productivity through automated numerical control (n.c.) tape or APT source code generation.
5. Increased productivity through easier access to archived drawings (represented digitally).
6. Increased productivity through computer generated 3-D modeling for installation and general configuration analysis.
7. Better quality designs through improved designer creativity provided by the man-machine interface.
8. Better quality drawings, less errors, more standardization.
9. Closer to optimal layouts (flat pattern) resulting in reduced waste and cutting time.
10. Increased productivity resulting from a rethinking of the way elements are designed. Design, manufacture and maintenance will marry, resulting in a better product from the freer transfer of knowledge.
11. Increased productivity in maintenance areas (rework, overhaul) through more efficient work scheduling and reduction of redundant and/or interfering operations.
12. Increased productivity through automated technical publication and other documentation authoring and updating.
13. Better accuracy in element fabrication resulting in reduced assembly time.
14. Increased manpower available to refine and improve work methods.
15. Improved communication in organization resulting from "everyone working on the same plan" which also results in organization cohesiveness.
16. Establishment of a common engineering data base for use in construction and management of ships over their lifetimes.
17. Attracting and maintaining quality engineering personnel.
18. Better handling of "crash" jobs and manpower/workload fluctuations (reduced overtime and farm-out).
19. Potential elimination of all paper representation or at least reduced space required for drawing storage.
20. Establish the organization in a leadership role in an emerging technology.

TABLE IV

Relevant Benefits of The Status Quo

1. No transition to a new system and the associated problems.
2. No new equipment procurement, maintenance or support costs.
3. Known costs.
4. No chance of obsolescence after procurement.
5. Large numbers of job types (numerical control programmers, draftsmen, etc.) left intact.
6. System is relatively secure.

B. TANGIBLE BENEFIT QUANTIFICATION

The desired output of a tangible benefit model is some type of information the decision maker can use to balance against the cost of the decision. "Cost" is a generic term, but for most decisions in which economic analysis would apply, it is taken to be monetary in nature with the accepted yardstick being dollars. The problem that often arises is that dollar savings cannot be measured directly. However, we can measure the time savings gained from a particular alternative. Two examples of the types of time savings gained are shown. Figure 5.1 [Ref. 12: pp.17] shows the time savings from a computer-aided drafting system, while Figure 5.2 [Ref. 20: pp. 31] shows the time savings from computer-aided NC programming. Time can then be utilized as the common denominator in the benefit quantification. This tends to allow for easier data collection, and the calculation of the time savings benefit which can be converted to dollar savings by the appropriate labor rates.

We have seen from Chasen [Ref. 10] and Shah [Ref. 12] that the savings in man-hours achieved in an application area for any given period can be represented as the difference between the time spent accomplishing the design or

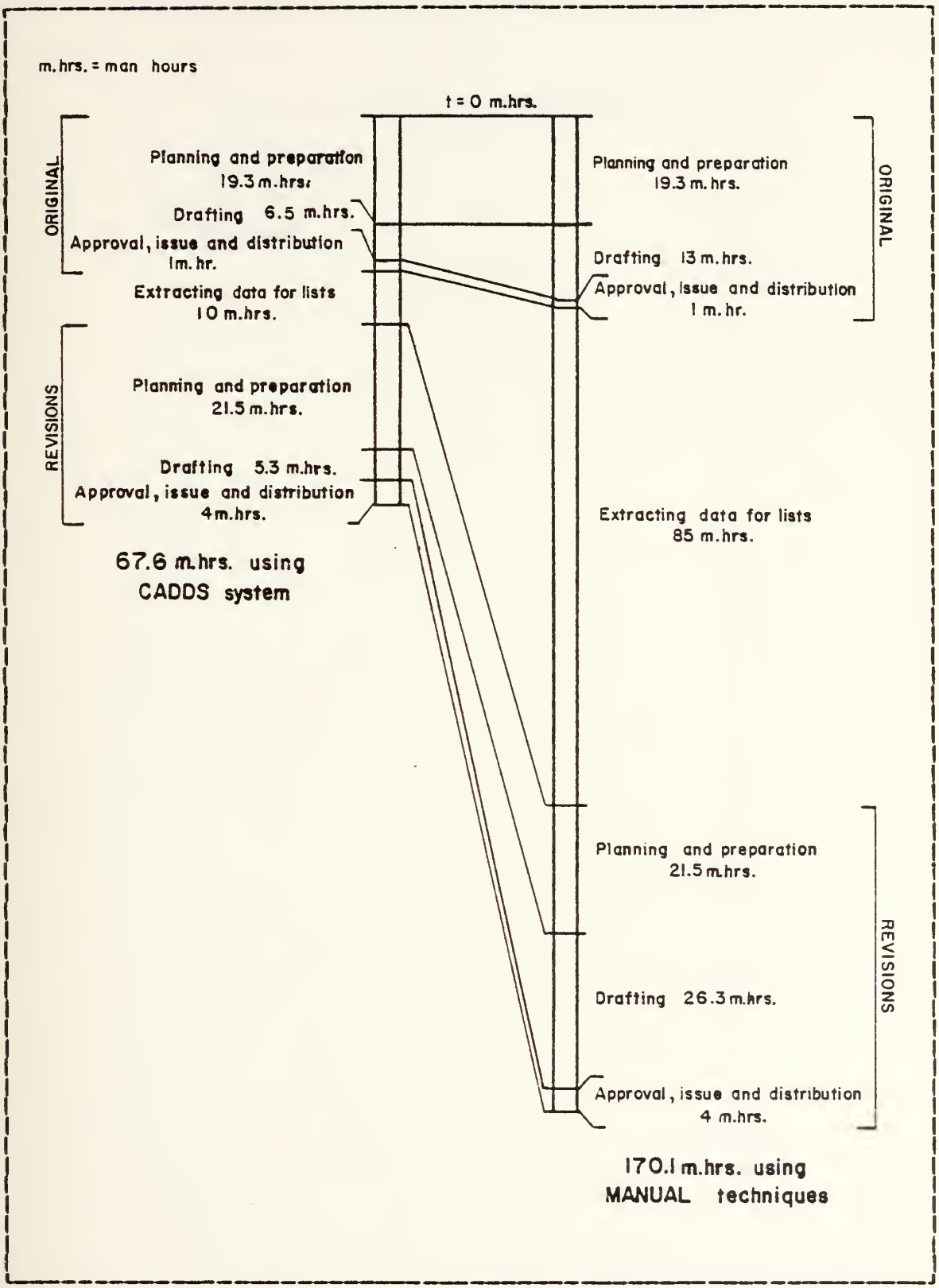


Figure 5.1 Time Flow for Generating An Elementary Design

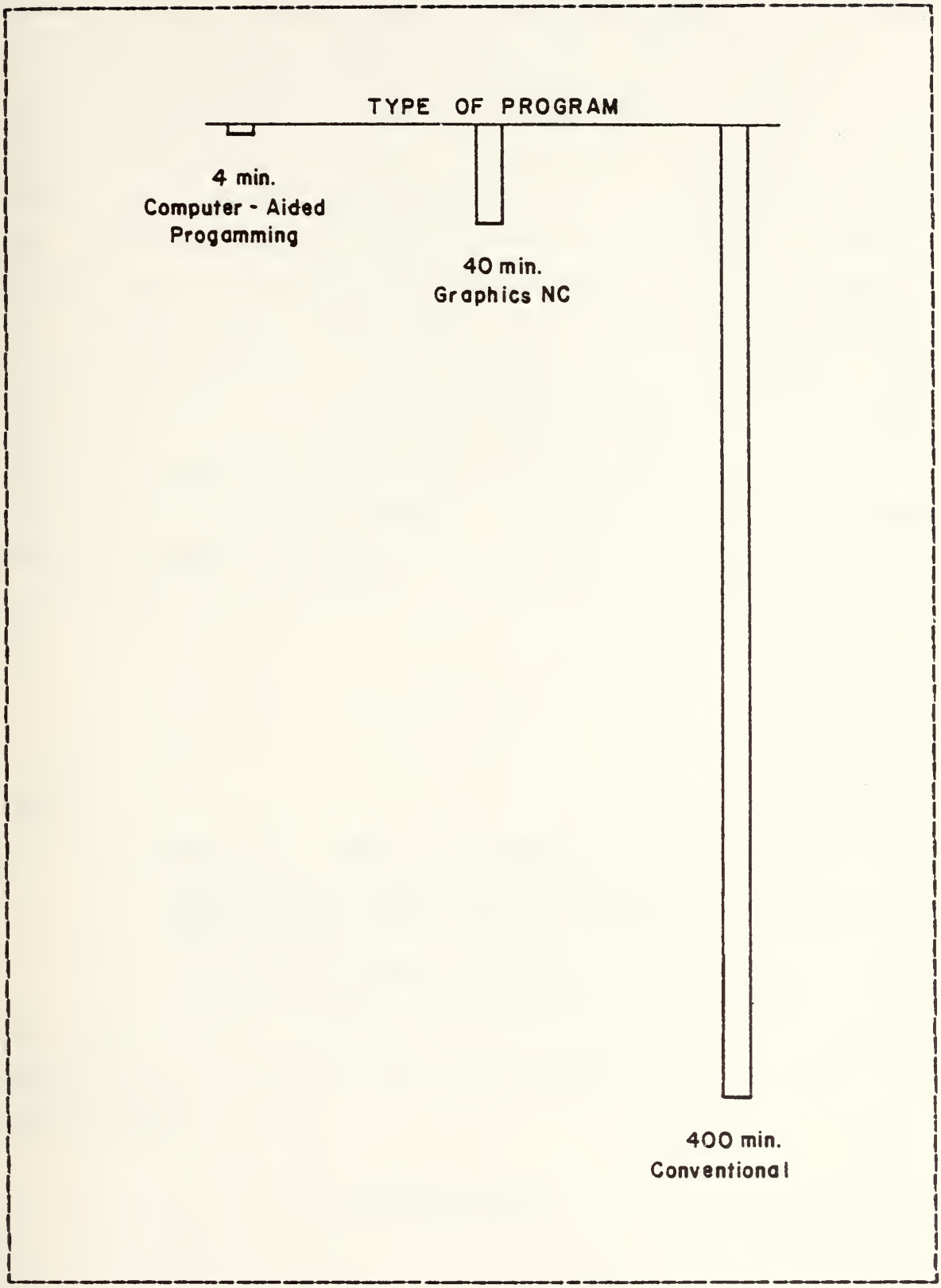


Figure 5.2 Time Required to Program One Tool Detail

manufacturing project manually and the time spent accomplishing the same project using the CAD/CAM system. A distinction is made between benefits incurred with CAD and those incurred with CAM even though there are application areas both have in common. For example, there may also be design and drafting requirements in a manufacturing shop. This separation of CAD and CAM is done primarily to reflect present-day thinking and data collection. With the creation of a single digital data base, CAD and CAM must be combined if the true potential of the system is to be realized. This rethinking will take time as old barriers are broken down and better working relations between design, manufacture, and maintenance operations are established. Meanwhile, in an effort to make the models more accurate to the present day, the separation will be maintained.

The generic framework for both CAD and CAM time savings is:

$$TB = M - S \qquad \text{(eqn 5.1)}$$

where

TB=Benefit in man-hour savings,

M=Estimate of the man-hours required to accomplish the project using manual design and manufacturing techniques, and

S=Actual man-hours required to accomplish the project using the computer-aided system.

The model can be improved by the addition of an operator efficiency correction term [Ref. 12], if learning curve data is available:

$$TB = M - (S \cdot E) \qquad \text{(eqn 5.2)}$$

where the new term, E is the fractional efficiency rating of a user of the particular CAD/CAM system. An example of why this correction is important involves two users of a particular CAD/CAM system. Both designers are experts at manual design techniques. Designer A has only had six months of experience on the CAD/CAM system and is considered to operate the system at 50% capacity. Designer B has had considerable experience on the CAD/CAM system and is considered to operate it at 100% of its capacity. They work on two separate but similar projects that each estimates should take eight hours to complete using manual design techniques. Designer A finishes his project on the CAD/CAM system in six hours, while Designer B finishes his in three hours. From equation 5.1 the total benefit from both projects attributable to the CAD/CAM system is seven man-hours ((8-6)+(8-3)=7). This yields a productivity ratio of 1.78:1 for the CAD/CAM system. Using equation 5.2, the total benefit is ten man-hours ((8-(.5x6))+(8-(1x3))=10). This yields a productivity ratio of 2.67:1. Which is a better estimate of the productivity gain attributable to the CAD/CAM system? The second, because the first penalizes the system for Designer A's inexperience. The reason for the benefit analysis is to compare systems, manual vs. CAD/CAM, not designers. The efficiency correction brings all users of the CAD/CAM system to an expert level, which is fair since the comparison is to an estimate based on an expert user of the manual design system. An example of the data reduction process utilizing the efficiency correction is shown in Figure 5.3.

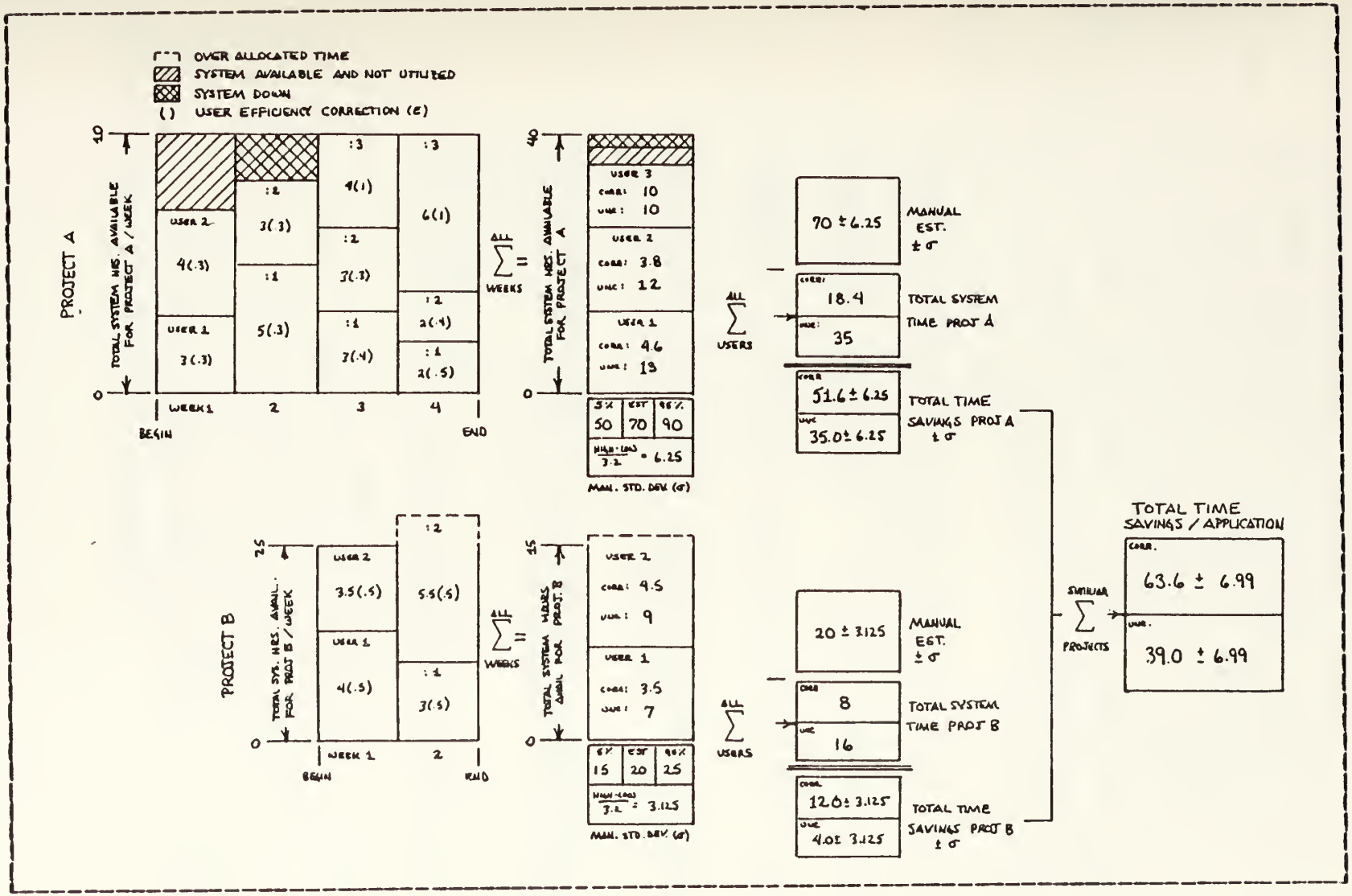


Figure 5.3 Sample Data Reduction Scheme

The above is essentially the model developed by R. Shah and G. Yan [Ref. 12] for 2-dimensional drafting applications. The model has been generalized to apply to several applications relevant to CAD or CAM. Unfortunately, the models still give a conservative estimate of benefit by only quantifying the time saved in the design, drafting or manufacturing processes. Both fail to capture some key elements to productivity inherent in the Interim CAD/CAM Systems.

The key elements of productivity associated with CAD/CAM on the Interim System are:

1. Quality (CAD/CAM)
   the ability to produce "better" designs through the exploration of many alternatives.

2. Flexibility (CAD/CAM)
   the ability to rapidly change an existing design for a new application.

3. Accuracy (CAD/CAM)
   a reduced error rate and the ability to rapidly correct those errors that do occur.

4. Transferability (CAD)
   the ability to rapidly transfer designs to and from archiving facilities. This includes the transformations between the storage medium and the user mediums.

5. Automization (CAM)
   the systems ability to automatically produce numerical control tapes and/or the APT source code, to drive the numericallly controlled manufacturing process.

6. Simulation (CAM)
   the systems ability to simulate 3-D mock-ups for installation and general configuration analysis.

Any particular prcject done on the Interim System will have one or more of these elements. If we keep in mind that each element represents a subset of the total project, then the discussion of each subset and its quantification will be easier to follow. Each element will be discussed individually with the necessary modifications to the generic benefit model following the discussion.

1. Quality

The first element is an expression of quality. The benefit from the element of quality is multi-faceted and can be quantified in any number of functional forms. One possible quantification is presented here. If one accepts the assumption that the designer will select the best design of those created or reviewed, and that up to some point, the greater the selection the better the design will be, then counting the number of those alternatives, and using it as a multiplicative factor will yield a proxy* measurement of the quality of the design.

Critics would point out that this type of measurement penalizes the good designer who produces high quality work with a minimum number of alternatives and rewards a poor designer who explores an exorbitant number of alternatives and produces good work. It can be argued, however, that the poor designer working on the system will actually improve his skills as he is able to rapidly discard poor alternatives and explore new ones. In a very short period of time, he will have reinforced the good design skills and be pursuing those alternatives he has learned will be beneficial. He is now at the level of the good designer who will use the capabilities of the system to be innovative. Innovation in design is where real gains in productivity and other long term non-quantifiable benefits are reaped in the total design, manufacture and maintenance process. For those reasons, counting the alternatives explored is a simple but representative way to quantify quality. This applies more directly to CAD; however, in the manufacturing environment there is a certain amount of design work performed that would be applicable.

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*Proxy in this sense means an artificial measure used to represent an actual quantity that cannot be quantified directly.

2. Flexibility

The second key element to CAD/CAM productivty is the ability to rapidly change an existing design for a new application. The model thus far developed deals with pure design and the resulting drafting applications. We will now look at the time benefit gained from computerized design within an existing "family" of designs.

The existence of the "family" of parts and their engineering data base allows instantaneous entry and revision of the particular family member. Using manual techniques, the drawing(s) and analysis data must be reviewed, sketches drawn and when the change is finalized a new set of drawings and engineering analysis data generated. Using parametric methods, a family member can be selected, parameters changed as required, analysis performed and drawings generated in a semi-automatic interactive mode which should be much faster than manual methods currently in use.

3. Accuracy

The third key element to CAD/CAM productivity is in the area of accuracy. Designs produced on the Interim CAD/CAM System should have fewer errors because of the reduced opportunity for the human element to make them. Conversion of the error rate as a measure of accuracy to the common denominator of time is accomplished by taking the time spent correcting errors using manual techniques and subtracting from that the time spent correcting errors using the Interim CAD/CAM System.

4. Transferability

The fourth element in CAD/CAM productivity deals with the mass storage and retrieval aspects of an Interim CAD/CAM System. Present technology storage systems usually

involve cataloging some sort of microform. Preparation of this microform is usually done at the user site. Then, it is shipped to the storage facility. Present technology offers a variety of ways of transferring a digital data base to a storage facility. The data can be read to a magnetic tape or optical disk and shipped, or a direct link from the user's computer to the storage computer via satellite or phone line can be established and the data passed. This method affords the opportunity of real-time updating, thus bypassing the problem of the archive maintaining the correct revision of the design.

5. Automization

The fifth key element can be quantified as the difference between the time taken to generate a numerical control tape using manual methods and the time taken to generate a numerical control tape using an Interim CAD/CAM System. Both times should reflect programming, validation and run times to capture the time benefit gained by optimal cutter path routing.

6. Simulation

The sixth key element can be quantified as the difference in the time required to design, construct and utilize 3-D models or mock-ups for installation and general configuration analysis, and the time to design, construct and utilize the same configuration digitally on the Interim CAD/CAM System.

Present manual methods of configuration analysis involve the dockside creation of full scale wood mock-ups followed by insertion of the various new components to check if they can be installed as desired. The CAD/CAM systems ability to generate 3-D models provides a tool to simulate the environment and the component insertion without full scale mock-up construction.

Quantifying these six key elements in the generic model is accomplished by quantifying each element individually and then simply summing to get the total benefit from a given project. The first element is represented by equation 5.3:

$$TB_1 = (M_1 \cdot MA) - ((S_1 \cdot SA) \cdot E_1) \qquad \text{(eqn 5.3)}$$

where

TB_1 = Total benefit from the quality element,

M_1 = Estimate of the time spent on a project using manual techniques in pure design,

MA = The number of alternatives explored using manual techniques,

S_1 = The time required to complete pure design aspects of the project,

SA = The number of alternatives explored on the CAD/CAM system, and

E_1 = The measure of user efficiency in pure design on the system ($0 \leq E \leq 1.0$).

To represent the remaining elements the generic framework is simply subscripted (i≠1):

$$TB_i = M_i - (S_i \cdot E_i) \qquad \text{(eqn 5.4)}$$

for i=

2: Flexibility

3: Accuracy

4: Transferability

5: Automization

6: Simulation

TB_i = Total benefit from the ith element,

M_i = Estimate of the time spent on a project using manual techniques in element i activity,

S_i = The time required to complete element i activity of the project, and

E_i = The measure of user efficiency in element i activity on the system ($0 \leq E \leq 1.0$).

Adding across the elements provides the total project benefit, (TPB):

$$TPB = \sum_{\text{all } i} TB_i \qquad \text{(eqn 5.5)}$$

A data reduction scheme showing the subsets is shown by Figure 5.4.

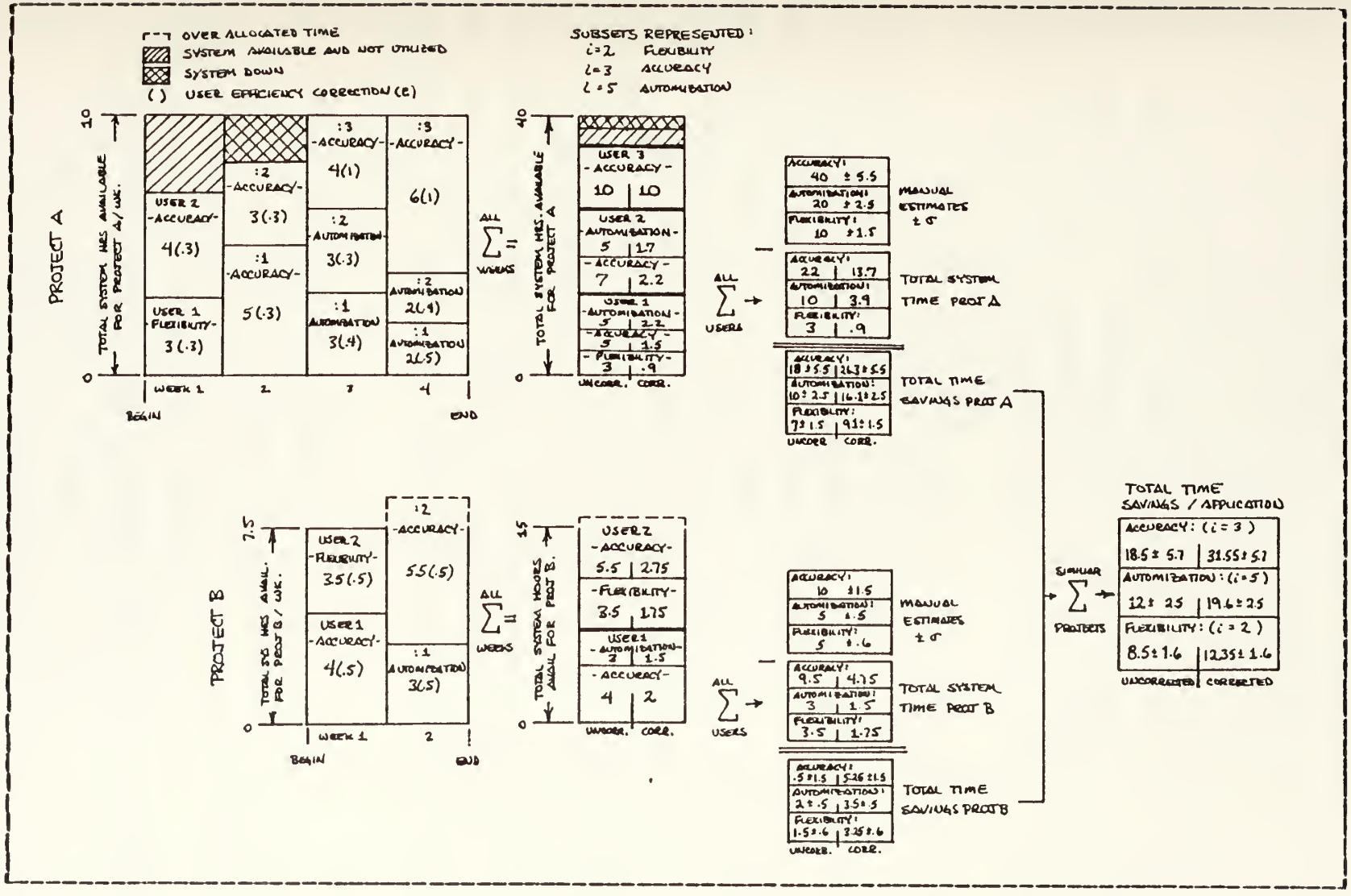

OVER ALLOCATED TIME
SYSTEM AVAILABLE AND NOT UTILIZED
SYSTEM DOWN
( ) USER EFFICIENCY CORRECTION (E)
SUBSETS REPRESENTED:
i=2 FLEXIBILITY
i=3 ACCURACY
i=5 AUTOMATION
PROJECT A
TOTAL SYSTEM HRS AVAILABLE FOR PROJECT A/WK.
USER 2 -ACCURACY- 4(.3)
USER 1 -FLEXIBILITY- 3(.3)
:2 -ACCURACY- 3(.3)
:1 -ACCURACY- 5(.3)
:3 -ACCURACY- 4(1)
:2 -AUTOMATION- 3(.3)
:1 AUTOMATION 3(.4)
:3 -ACCURACY- 6(1)
:2 AUTOMATION 2(.4)
:1 AUTOMATION 2(.5)
WEEK 1 2 3 4
BEGIN END
ALL WEEKS
TOTAL SYSTEM HRS. AVAILABLE FOR PROJECT A
USER 3 -ACCURACY- 10 | 10
USER 2 -AUTOMATION- 5 | 1.7
-ACCURACY- 7 | 2.2
USER 1 -AUTOMATION- 5 | 2.2
-ACCURACY- 5 | 1.5
-FLEXIBILITY- 3 | .9
UNCORR. CORR.
ALL USERS
ACCURACY: 40 ± 5.5
AUTOMATION: 20 ± 2.5
FLEXIBILITY: 10 ± 1.5
MANUAL ESTIMATES ± σ
ACCURACY: 22 | 13.7
AUTOMATION: 10 | 3.9
FLEXIBILITY: 3 | .9
TOTAL SYSTEM TIME PROJ A
ACCURACY: 18 ± 5.5 | 26.3 ± 5.5
AUTOMATION: 10 ± 2.5 | 16.1 ± 2.5
FLEXIBILITY: 7 ± 1.5 | 9.1 ± 1.5
UNCORR. CORR.
TOTAL TIME SAVINGS PROJ A
PROJECT B
TOTAL SYS HRS AVAIL. FOR PROJ B / WK.
USER 2 -FLEXIBILITY- 3.5(.5)
USER 1 -ACCURACY- 4(.5)
:2 -ACCURACY- 5.5(.5)
:1 AUTOMATION 3(.5)
WEEK 1 2
BEGIN END
ALL WEEKS
TOTAL SYSTEM HOURS AVAIL FOR PROJ B.
USER 2 -ACCURACY- 5.5 | 2.75
-FLEXIBILITY- 3.5 | 1.75
USER 1 -AUTOMATION- 2 | 1.5
-ACCURACY- 4 | 2
UNCORR. CORR.
ALL USERS
ACCURACY: 10 ± 1.5
AUTOMATION: 5 ± 1.5
FLEXIBILITY: 5 ± .6
MANUAL ESTIMATES ± σ
ACCURACY: 9.5 | 4.75
AUTOMATION: 3 | 1.5
FLEXIBILITY: 3.5 | 1.75
TOTAL SYSTEM TIME PROJ B
ACCURACY: 5 ± 1.5 | 5.26 ± 1.5
AUTOMATION: 2 ± .5 | 3.5 ± .5
FLEXIBILITY: 1.5 ± .6 | 3.25 ± .6
UNCORR. CORR.
TOTAL TIME SAVINGS PROJ B
SUMMER PROJECTS
TOTAL TIME SAVINGS / APPLICATION
ACCURACY: (i = 3)
18.5 ± 5.7 | 31.55 ± 5.7
AUTOMATION: (i = 5)
12 ± 2.5 | 19.6 ± 2.5
FLEXIBILITY: (i = 2)
8.5 ± 1.6 | 12.35 ± 1.6
UNCORRECTED CORRECTED

Figure 5.4 Data Reduction With Subsets Included

It can be seen that productivity ratios can be developed for each elemental activity as well as the aggregate ratio for the entire project. This provides a management tool for monitoring productivity in each project as well as the much needed [Ref. 16: pp. 1] verification of the vendors' claims to productivity gains available from the CAD/CAM system. This ratio can then be used in standard economic analysis procedures to estimate dollar-savings, and hence return on investment, payback periods, etc., required in the acquisition process.

A possible embellishment of the model would be the inclusion of an estimate on the standard deviation of M, which is the estimate of the total project time using manual techniques. This can be accomplished by taking the difference of the ninety-fifth percentile estimate and the fifth percentile estimate of the time required for the project, and dividing it by 3.2 [Ref. 21]. This will give a rough cut at the standard deviation which can be squared to get the variance estimate. If one were to use the estimated time to accomplish the project manually, the upper estimate (+1 standard deviation) and the lower estimate (-1 standard deviation) as three points in the data reduction scheme, the user would end up with three productivity ratios. This represents the high, mean and low levels of productivity one might expect.

C. INTANGIBLE BENEFIT ANALYSIS

Thus far we have attempted to quantify the first nine of the twenty benefits listed in Table III. Those benefits and their respective quantifying element(s) were:

1. Increased productivity (reduced man-hours to accomplish task) through automation of repetitive time-consuming tasks;
   QUALITY, FLEXIBILITY, ACCURACY
2. Increased productivity through the ability to rapidly produce a design from existing generic element designs;
   FLEXIBILITY

3. Increased productivity through the ability to rapidly edit existing designs;
QUALITY, FLEXIBILITY, ACCURACY

4. Increased productivity through automated numerical control tape or APT source code generation;
AUTOMIZATION

5. Increased productivity through easier access to archived drawings represented digitally;
TRANSFERIBILITY

6. Increased productivity through computer generated 3-D modeling for installation and general configuration analysis;
SIMULATION

7. Better quality designs through improved designer creativity provided by the man-machine interface;
QUALITY

8. Better quality drawings, fewer errors, more standardization;
ACCURACY

9. More optimal layouts (flat pattern) resulting in reduced waste and cutting time;
AUTOMIZATION

Some of the benefits are only partially represented. For example, benefit nine also includes "reduced waste," which is not captured by the time difference in automization while reduced cutting time is. The remainder of this chapter will be devoted to discussing the remaining benefits in Table III.

1. Rethinking of Design, Methods

Benefit number ten, "the increased productivity resulting from a rethinking of the way elements are designed," is in reference to the use of a common engineering data base, in digital format, that can easily be shared between design, manufacture and maintenance activities. Design problems can be quickly identified by manufacturing engineers and easily corrected. Fleet user suggestions can also be incorporated much faster. This interaction between designer, manufacturer and user is one of the primary long range benefits of a CIDMM system. Today with the Interim CAD/CAM System the interaction is generally

confined betweeen designer and manufacturer. However, this is an improvement to the previous poor state of communication.

The quantification of rethinking design methods could be accomplished by surveying designers, manufacturers and users as to their impressions of what communication between groups is or could be like with the Interim CAD/CAM System. Questions like, "do you see an improvement in information flow occuring between design and manufacturing activies resulting from the Interim CAD/CAM equipment?" could be used to gather data on the expected level of information exchange. This is a reasonable measure since user expectations would probably tend to occur. For example, if the users expect the system to fail, it probably will. This is the argument of the self-fulfilling prophecy.

2. More Efficient Work Scheduling

Benefit number eleven, "the increased productivity in maintenance areas (rework, overhaul) through more efficient work scheduling and reduction of redundant and/or interfering operations," refers to the problems associated with different workshops all accomplishing their work from each individual shop's original drawings. For example, the air conditioning shop is tasked with installing a new compressor in a space. To install it, they have to cut a hole in the deck to lower it into the space. They finish installing it and weld the deck plate back into place. One week later the hydraulic shop wants to put a hydraulic pump in the space and has to also cut a hole in the deck. This redundant activity could have been avoided if both shops had daily access to the latest changes to the space. This access is easily accomplished through the use of a common engineering data base. Managers would have a means of tracking and thus coordinating the work effort.

The quantification of more efficient work scheduling could be accomplished by a survey of management to see if they believed having a daily view of the work proposed or in progress would be useful in their scheduling tasks. Questions like "do you see an improvement in productivity resulting from your ability to track or project the actual changes occuring in a space from your office on a daily basis?" could be used to gather data on more efficient work scheduling resulting from the CAD/CAM system.

3. Technical Publication Changes

Benefit number twelve, "the increased productivity through automated technical publication and other documentation authoring and updating," deals with the Interim CAD/CAM Systems capability to update fleet technical publications in almost real-time, instead of the months it currently takes, "update," in this sense, referring to text and illustration changes. The benefit as it would be realized with the Interim CAD/CAM System would be the reduced time required to transfer the latest engineering drawings to the publishing agency for incorporation into the appropriate reference manuals and other technical publications. The greatest realization of benefit would occur on the publishers' end, where they would be able to instantly access the digitized drawings, edit them for appropriate figure layout, and print them. This would require them to have a compatible CAD system, but I submit that if the digital drawings were available, it would not be long before the publishing agencies gained the ability to use that data.

Quantification of the time savings could be done as a tangible benefit to the Navy but would not specifically apply to the Naval Shipyards. What does apply, though, is the shipyards ability to rapidly issue engineering changes to the fleet user and begin receiving feedback from them.

Quantification of these types of benefits could be acccm-plished through survey of the users with questions like "do you anticipate a shorter time delay in implementing design and engineering changes into the technical publications as a result of the digitized data base and Interim CAD/CAM System?" A follow-up question to see if a productivity gain is not foreseeable with the Interim CAD/CAM System, but is forseeable with the implementation of a Navy wide CAD/CAM system could be "do you anticipate a shorter time from design and engineering change to technical publication incorporation of thcse changes resulting from a compatible Navy-wide CAD/CAM capability?"

4. Improved Accuracy in Fabrication

Benefit number thirteen, "better accuracy in element fabrication resulting in reduced assembly time," deals with the increased accuracy in fabrication and hence the improve-ment in fit of all the parts when assembled. This is almost a quality assesment cn the manufacturing side of the CAD/CAM relationship. This could be quantified with the tangible generic framework if applied to a assembly line type of activity. The shipyards, however, deal with "one of a kind" manufacturing and repair, requiring a more subjective assessment of how well things designed and manufactured on the CAD/CAM system go together.

Questions such as "have you noticed an increased quality of fabricated parts and finished products?" followed by "do you attribute this wholely or at least in part to the implementation of the Interim CAD/CAM System?" Clearly the people who are trying to fit Plate A and Plate B together with Plate C will have an opinion on the accuracy of the manufacture of those pieces.

5. Refine and Improve Work Methods

Benefit number fourteen, "the increased manpower available to refine and improve work methods," deals with the ability of the users of the Interim CAD/CAM System to convert their new found spare time, if any, into improved work methods in areas not adaptable to CAD/CAM use, or in areas where innovative application of the technology could be beneficial. Realization of this benefit will directly depend on the attitude of the users toward the system and their ability to use some of the "spare time" for innovative activities. Both of these elements will depend on how management has implemented the CAD/CAM system in the workplace. This benefit could be quantified through counting the increase or decrease in suggestions submitted. However, this is somewhat unreliable, and may not have any bearing on the CAD/CAM system. A method that would work for measurement of attitudes is again the survey of all users and benefactors of the system. Questions like "are there any work methods that you have contemplated improving but have not had the time to follow them through?" followed by "do you think any time savings you realize would be applied to improving those previous identified work methods?", and finally, with an explanation, "if not, why not?" Here you would have an indication of a desire to change something for the better, an indication of time savings resulting from the CAD/CAM system, an indication of management's implementation policies, and, finally, an indication of exactly what the problem with management of the assets might be.

Care should be exercised in quantifying this benefit to avoid double counting the time savings. This time savings has been previously identified as a tangible benefit. The savings identified in this section would have to be subtracted from the savings previously defined in equations

5.1 through 5.4, before reporting the total time savings resulting from the CAD/CAM system. An alternate way to resolve this double counting conflict would be to assume the time spent refining and improving work methods using manual design and manufacturing techniques would be the same as the time spent using a CAD/CAM system. Since they are assumed equal, the benefit would not be time savings, but would be the contribution of "better" work methods brought about by the use of a "better" tool, the CAD/CAM system, with which to analyze the existing work methods. Just as one can build a house with an axe, a "better" house can be built using power tools. The new tools aid in the definition of the new methods that result in a "better" house.

6. Communication/Cohesiveness

Benefit number fifteen, improved communication in the organization which results in organizational cohesiveness deals with the improved communication and interaction of the design, manufacturing and maintenance users much as benefit number four did, but this time the benefit to be measured is not the free exchange of ideas but the user satisfaction which leads to organizational unity and cohesiveness. As it applies to the Interim CAD/CAM System, we could seek to measure the job satisfaction generated by a reduction in frustration caused by "everyone not working on the same plan." This also relates to benefits reaped from improvements in work scheduling, number six.

Quantification of job satisfaction is a major topic in many practical psychology books and is sometimes addressed under the subheadings "teamwork" and "morale." Dopico [Ref. 17: pp. 48, 51] develops a number of questions under both headings that gives an indication of the user's feelings about his satisfaction with the organization and his role as a user of the CAD/CAM system.

7. Engineering Data-base for Life-Cycle Management

Benefit number sixteen, "establishment of a common engineering data base for use in construction and management of ships over their lifetimes," deals with the long-range benefits to be derived from a common engineering data base created at initial design, utilized in construction, rework and overhaul, and day to day maintenance on the ships. This benefit is the cornerstone of the CIDMM concept but is also applicable now as the Navy begins to use CAD/CAM in its initial design efforts. This is a subjective assessment of future benefits perceived as accruing from this digital data base made possible by CAD/CAM. This would include things such as increased readiness through shortened overhaul time. There is a problem here though, in that those most capable of assessing the benefit of a common data base e.g., Shipyard Commanders, or Fleet Commanders, may not be versed in the capabilities of the CAD/CAM system, while those well versed in CAD/CAM's capabilities are not versed in the effect of, say, a 20% reduction in overhaul time on fleet readiness. With a little imagination though, I think questions could be developed that when posed to both groups, the fleet benefactors and the Shipyard CAD/CAM users, could be subjectively analyzed to give an indication of these types of benefits (readiness just being one example).

8. Quality of Engineering Personnel

Benefit number seventeen, "attracting and maintaining quality engineering personnel," deals with the benefits accrued from maintaining a trained engineering workforce as well as attracting new personnel. In the U.S. today, there is a shortage of engineering personnel. "Colleges and universities are not training enough new graduates in the needed time frame" [Ref. 3: pp. 49]. With the

engineering job market as competitive as it is and the government's traditionally low pay, U.S. Naval Shipyards will not stand a chance at any of the "best and the brightest" engineers unless they can offer an opportunity to work with the latest technology in the engineering sciences. A more troubling aspect of the problem, is the retention of qualified personnel who have developed an expertise in U.S. Naval Ship design, construction, repair and overhaul. The U.S. Navy simply cannot afford to loose this cadre of personnel. This is not to imply that making the commitment to CAD/CAM will ensure a steady stream of engineers, or the retention of existing personnel, but I think it is one of the most important and most overlooked benefits associated with CAD/CAM.

Quantification of the benefit is again through a survey of all the users. Questions like "is it important to you to work for an organization that is a leader in your technical field?", or "is (was) the Navy's involvement in CAD/CAM a factor in your decision to stay with (or to join) the U.S. Naval Shipyard Engineering force?" would give some indication as to how important, from a human resource point of view, it is for the Navy to pursue CAD/CAM.

D. OTHER BENEFITS

This section deals with the remaining benefits from Table III that do not seem to fit into the tangible measurement framework, or the intangible survey framework. Each benefit will be discussed and an appropriate quantification method suggested.

1. Reduced Material Wastes

This benefit deals with the reduction of waste material generated from flat pattern cut-outs. The use of

pattern layout optimization programs and numerically controlled flame cutting techniques should reduce the amount of scrap produced. Quantification is relatively easy, by measuring the amount of waste material generated. This amount can be converted to a "percent waste" which can be compared to previous waste data for an indication of waste reduction.

2. Manpower/Workload Fluctuations

The next benefit discussed deals with the proverbial problem of "crisis management"--the problems of unanticipated work associated with impossible deadlines. The result of this unanticipated tasking is a lot of overtime labor and "farming-out" of projects that cannot be accomplished internally. A reduction in overtime would save money as would a reduction in the number of farm-outs.

Quantification of the benefit can be accomplished by counting the number and cost of the projects farmed out as well as the amount of overtime being generated. The cost of farm-outs will have to be corrected to some base year dollars, but once that is done it will give an indicator in dollars of improvements in farm-out reduction. A useful statistic can be found by counting the number of farm-outs in a fixed time frame and then dividing that by an index project load. An example would be farm-outs per year per 100 projects which would reflect the influence of workload in the decision to farm-out.

3. Paper Elimination

This benefit simply addresses the gain in floor space attributable to the digital storage of drawings instead of the current methods. This will have the largest effect on the archiving facilities as their current micro form storage is replaced by magnetic tape, hard disk, or

optical disk mediums. At the Shipyard level the benefit will also be in square-foot savings, but on a much smaller level. I suspect any initial savings in storage will be offset by the space requirements of the CAD/CAM system. Quantification, if desired, can be accomplished with a simple relationship that yields storage space required as a function of the number and size of the drawings to be stored.

4. The Cutting Edge of Technology

This benefit deals with the advantages gained by an organization, in this case the Navy, from being a leading force in a technology. The most graphic example of this advantage comes from the civilian computer market with the IBM Corporation. There is little doubt that IBM is a leading force in computer technology. Because of this leadership, there is a great deal of interest by smaller companies software vendors, peripheral manufacturers, etc., to be "IBM compatible." IBM, through their leadership, has in effect created the defacto standard that others follow.

As was presented earlier, the U.S. Navy has a vested interest in the CAD/CAM technology and the direction the shipbuilding industry including repair/rework/overhaul is proceeding in this ccuntry. If the Navy hopes to influence that direction in their best interests, they will have to be a leader in the field. The areas of the technology that have already been identified to be in the Navy's best interest are: [Ref. 22: pp. 20]

1. Interoperability
2. Interchangeability
3. Defacto standardization

4. Electronic transferrence of all data, initially engineering date throughout the Material Command.

   a) Shipyards (public and private)

   b) Contractors

   c) Ordnance Labs

   d) Naval academia (USNA, NPS)

   e) All Systems Commands

   f) Potentially all Navy

Quantification of this benefit cannot be accomplished with measurements or surveys as it is simply too broad a concept to pin down. It must be left up to the reader at this point to visualize the entire technology, CAD/CAM today, CIDMM tomorrow, and in his or her own mind realize the tremendous potential presented.

E. SUMMARY

I hope that in this chapter you have seen the pieces of a methodology designed to measure the benefits from the Interim CAD/CAM System as well as a method that could be extended to measure the benefits of future developments in the technology. The next chapter will put the pieces together in a formal statement of the methodology and how it can be applied to the current shipyard environment.

VI. FORMAL METHODOLOGY

A. OVERVIEW

The preceeding chapter defined the pieces of Grahlman's method. This chapter will put those pieces together resulting in a sort of "road map" that describes how the user would implement the method. As stated before, the method has three distinct parts:

1. Tangible Benefit Analysis Using The Generic Framework
2. Intangible Benefit Analysis
3. "Other" Benefit Analysis

Each part has its own data collection and analysis techniques which will be detailed in this chapter.

B. TANGIBLE BENEFIT ANALYSIS USING THE GENERIC FRAMEWORK

1. Data Collection

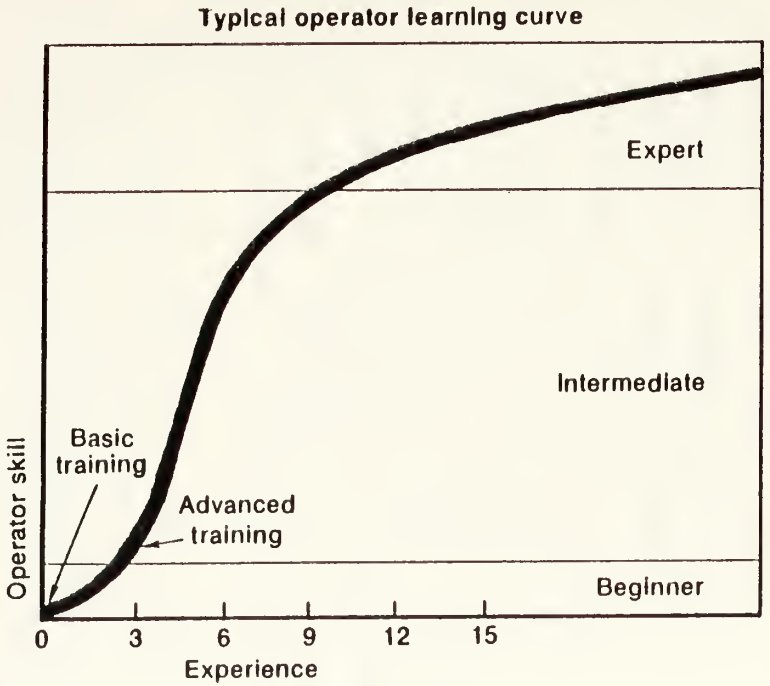
The generic model developed for quantification of the tangible benefits requires an estimate of the time it takes to accomplish the project using manual techniques. In addition to this point, estimates of the longest (95th percentile) and shortest (5th percentile) possible times are required to establish an approximation of the standard deviation of the original estimate. These estimates should be made by the person most familiar with the project requirements and most familiar with the time required to accomplish the project using manual techniques. This person is most likely the shop supervisor. An alternative to this estimating method would be to use the Computer-Aided Time Standards System, which is designed around the the Defense Work Measurement Standard Time Data (DWMSTD) [Ref. 23].

This contains time estimates for accomplishing various tasks. A total project estimate could be determined by combining the estimates of its composite tasks. It is this authors belief though, that the shop supervisor's estimate would be more accurate. Unfortunately, no data currently exists tc substantiate that belief.

Further refinement of the productivity information into the six key areas identified would require the individual users to make their own estimates of the time required to accomplish the particular task manually. High and low estimates could also be made and standard deviations computed.

Either method of estimating the manual time could be used depending on the user's goals for the benefit analysis. For the March 1984 Naval Materiel Command Report, the first method is probably adequate. Actual collection of the time estimates in either case could be accomplished automatically by responding to programmed query by the system at log-on or by a data collection form that would accompany each project.

Collecting the actual system time required to complete the project can be done automatically within the system. When a user logs onto the system, the project and nature of the session, e.g., error checking and correcting, can be recorded providing a means of collecting data under the heading "Accuracy." At log-off, the system can automatically perform the required accounting of user/project/subset information. Again, the subset information is nice to have, but not essential to the actual productivity measurement. Thus far, we have the four pieces of data required to use the data reduction scheme for determining the uncorrected time savings per project. Use of the data reduction scheme will be detailed in the next subsection.



A typical novice operator of a computer-graphics system passes through four stages of training during the first 18 months:

- **Under 3 months** — During this period, symbol libraries, command menus, and accounting procedures are developed as the system operators familiarize themselves with the equipment. With the exception of extremely gifted or previously trained operators, no productivity increases should be expected.
- **3 to 9 months** — The basic libraries and operating procedures should be established and operators should be reasonably familiar with the command language of the system. A modest savings in design and drafting time over previous techniques should be evident.
- **9 to 15 months** — Operators should be up to full speed and completing even the most complex drawings with relative ease. Shortcuts to production are learned, and the most dramatic productivity increases will occur in this period.
- **Over 15 months** — Further acceleration of turnaround time will occur in this period. This comes not so much from increased operator speed and efficiency, but from improvements in system utilization, task prioritizing, and staff organization, as well as from new software and hardware features that allow the system to handle additional tasks.

Figure 6.1 Computervision Learning Curve

To determine the corrected time savings, a user efficiency factor must be determined. This is accomplished with the user learning curve data supplied by the vendor. In the case of the Interim CAD/CAM System, that would be Computervision. In my research I was unable to obtain specific data upon which Computervision based their CAD system learning curve, Figure 6.1 [Ref. 24]. Although not accurate enough to be used, it shows the general shape of CAD/CAM learning curves. As shown in the figure, operator skill (efficiency) is a function of experience (time) on the system. This relationship can be described mathematically and once determined, can be used to compute the desired efficiency correction factor. Collection of this data can either be done manually with the project data sheet or automatically by the system.

2. Analysis

Analysis of the time data is accomplished through the data reduction schemes previously shown. The first scheme discussed is shown in Figure 5.3. In it, the time spent on a project per week per user is tracked across the duration of the project. Also available, but not required for the computation of time saved, is system utilization data. At any stage of the project the time spent per user can be computed by summing that user's account on the project to date. To compute the corrected time spent, each week's time must be multiplied by the applicable efficiency factor, in parentheses, before summing across the weeks for each user.

Now, assume that the shop supervisor is the person estimating the manual times. To compute an estimate of the standard deviation of the supervisor's estimate, the 95th percentile is subtracted from the 5th percentile and divided by 3.2 as previously discussed in Chapter 5. The total

system time required for the project is found by summing across all the users. This is then subtracted from the estimated time to complete the project using manual techniques, yielding a total time savings for the project and an estimate of its accuracy.

At this point, similiar projects are grouped into application areas such as 2-D drafting, piping, etc. The total time savings per application is found by summing across all the projects in the group. To obtain an estimate of the standard deviation of this total time savings, the standard deviations of each project are squared then summed (the variance of a sum is the sum of the variances assuming independence). This sum is converted back into a standard deviation by taking its square root. This technique can be applied to get the total time savings by summing all the projects instead of by application group, if desired.

The second scheme includes the subsets and is shown in Figure 5.4. Data reduction is essentially the same, except each user has potentially six subset accounts that must be tracked. If the user is estimating his own manual times, each subset will have an associated standard deviation estimate. The subsets are then summed across the users to get a total system time per subset. In this way, the result is a total time savings per subset per project. From either time savings (subdivided or not) productivity ratios can be computed which could be useful in future economic analysis involving CAD/CAM in the shipyard environment.

C. INTANGIBLE BENEFIT ANALYSIS

1. Data Collection and Analysis

The intangible benefit data is collected from the results of a questionnaire customized to the shipyard environment. The questions generated should cover the benefit areas discussed in Chapter 5. The perceptions of the benefits will differ with different groups of people. The questions are grouped using the cluster analysis techniques described in Chapter 5 and Dopico [Ref. 17]. Once the groups have been formed and the leftover "other" benefit catagories identified, analysis of the results can begin. This analysis consists of submitting the raw data to a boxplot routine which computes the median and quartiles. This information is then displayed on a system comparison plot similiar to that found in Figure 4.3.

D. "OTHER" BENEFIT ANALYSIS

1. Data Collection and Analysis

a. Tangible Benefits Not-Quantifiable Using the Generic Framework

Data for these benefits should be available through the appropriate accounting branches. This data should be collected and analyzed to determine if any reduction in waste material, farm-outs or overtime in their respective areas could be attributable to the Interim CAD/CAM System.

b. Non-Quantifiable and Intangible Benefits

Data collection has already been accomplished through the questionnaire. Analysis of this data will consist of computing the means and standard deviations of

the samples, each question representing a sample. These statistics and their contribution to the benefits they describe should be thoroughly discussed.

At this point in the overall benefit analysis, the user of the methodology could discuss any benefits not previously discussed. This will generally be in the form of subjective logical argument.

E. SUMMARY

A summary of the methodology is presented as a flowchart shown in Figure 6.2. It is the hope of this author that the methodology presented will establish a useful framework for the systematic and thorough benefit analysis of not only the Interim CAD/CAM System but also future systems catagorized under the acronym CIDMM.

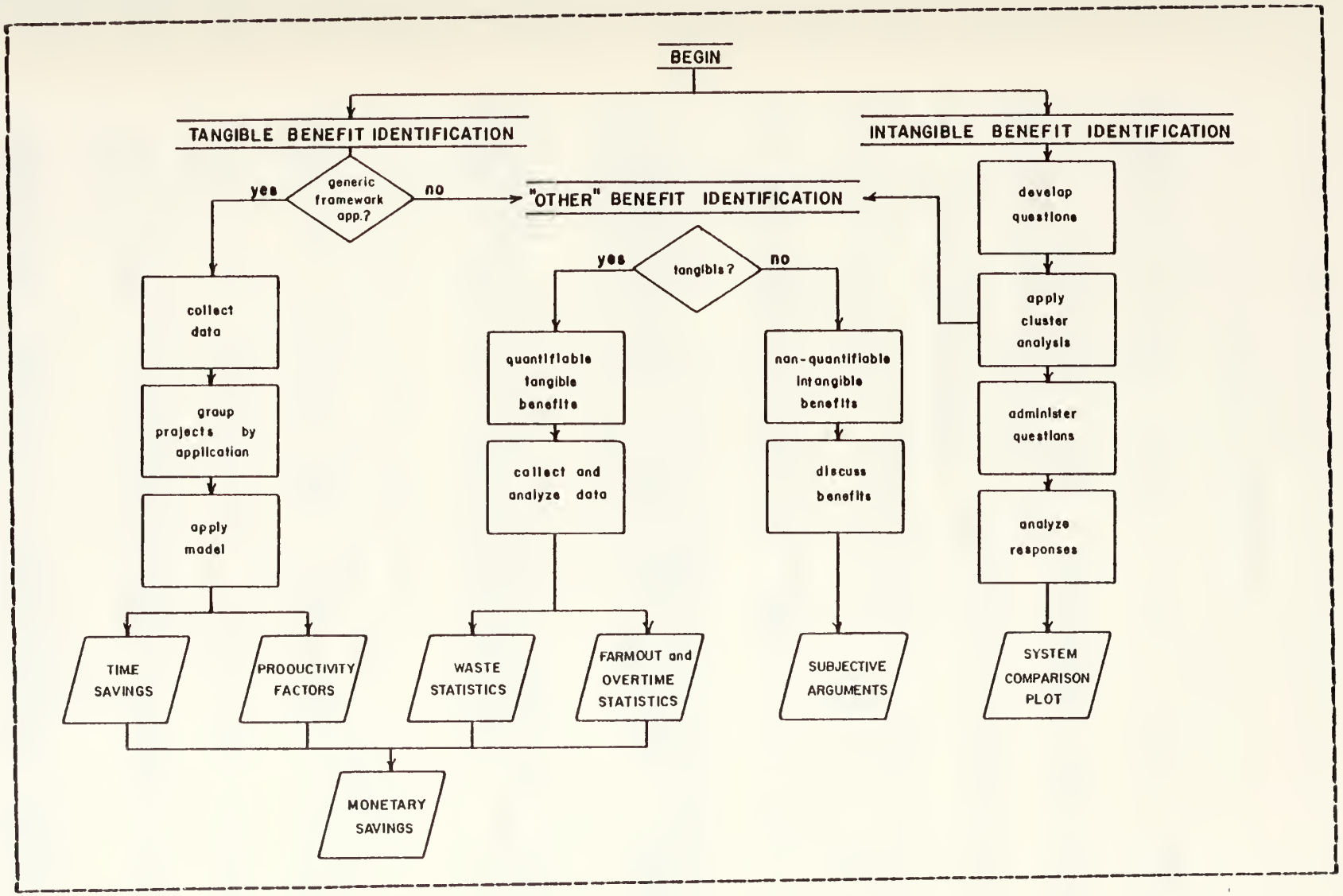


Figure 6.2 Methodology Flowchart

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